Machine Model Parameter Determination User Manual

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List of Definitions

- Block diagram – A visual method commonly used in engineering to depict the relationship between inputs and outputs of a system.
- GUIDE – Graphical User Interface Development Environment – A Matlab toolbox that supplies a graphical and interactive method for the creation of graphical user interfaces.
- Initial Conditions – Values that determine the simulation's starting point.
- Matlab – A software package developed by Mathworks that is commonly used for engineering computation.
- Matlab Workspace – The location where all variables are stored.
- Physical test results – These are the results of actual generator performance as physical measured in the field.
- PSLF – (Positive Sequence Load Flow) – A software tool manufactured by General Electric that is used by power systems engineers to analyze the performance and security of large interconnected power systems.
- PSLF test results – These are the results of control simulations run using PSLF.
- Semi-real time – Result updates appear after the user selects the run command.
- Simulink – A Matlab toolbox that allows users to build and analyze block diagrams.
- Simulink test results – These are the results obtained using the group created Simulink tool.

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1 Introduction

This software was developed by a team of students at Iowa State University and engineers in the Infrastructure business unit of General Electric. It is intended to assist engineers in more quickly determining accurate model parameters for use in computer simulations. It was developed for use in the power industry, specifically the parameters associated with synchronous machine modeling, but has a variety of possible applications.

1.1 Purpose and Intended use of this Manual

This document is intended to be used as a guide both to both the use and maintenance of the software. It includes instructions on the basic use, provides a detailed and technical overview of the program structure, instructions for adding models to the library, detailed examples of adding models to the library, and the source code. It is assumed that the reader is very familiar with Matlab.

1.2 Acknowledgments

The project team would like to thank Doug Welsh, Juan Sanchez and Dan Leonard of General Electric and Dr. Chen-Ching Liu of Iowa State University for the assistance and technical expertise that they have provided.

2 Basic Use

This section provides instructions for the basic use of the software including, initial execution, running both normal and batch simulations, loading test data, saving and loading parameters, and exporting graphs and simulation data.

2.1 Starting Program

To start the program, open Matlab and change the Matlab directory to the directory directory containing the program files. This is shown in Figure 2.1.

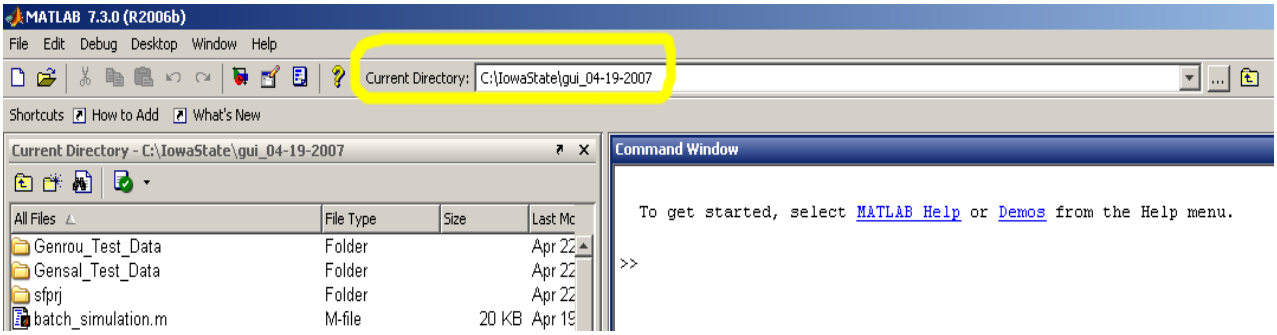


Figure 2.1 Changing Matlab Directory

In the current directory portion of the Matlab window, select main_window.m and right click. Select “Run.” This is shown in Figure 2.2.

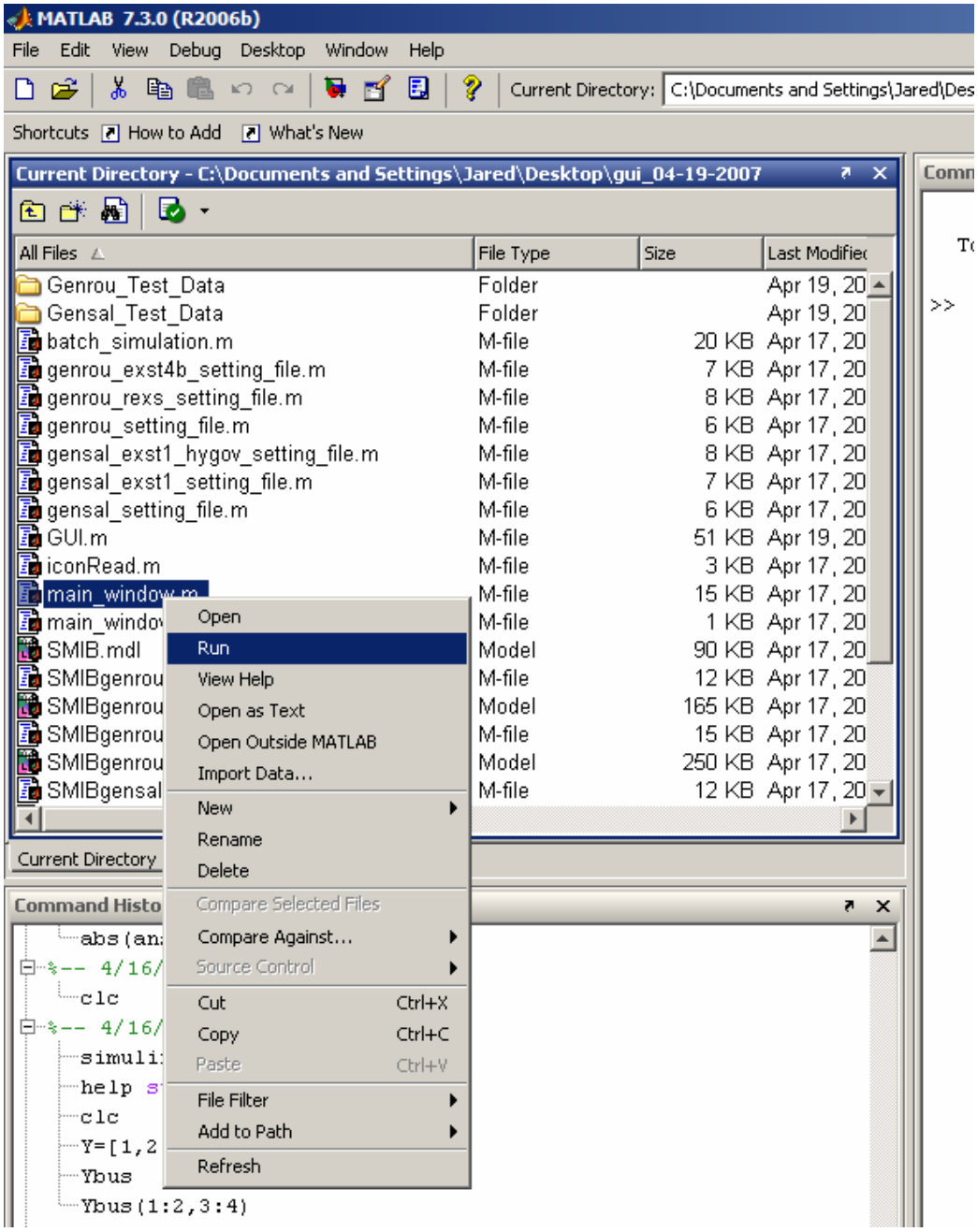


Figure 2.2 Running main_window.m

The opening window will appear. A list of all of the models currently in the library will be in the center select a model and press “Open.” This is shown in Figure 2.3.

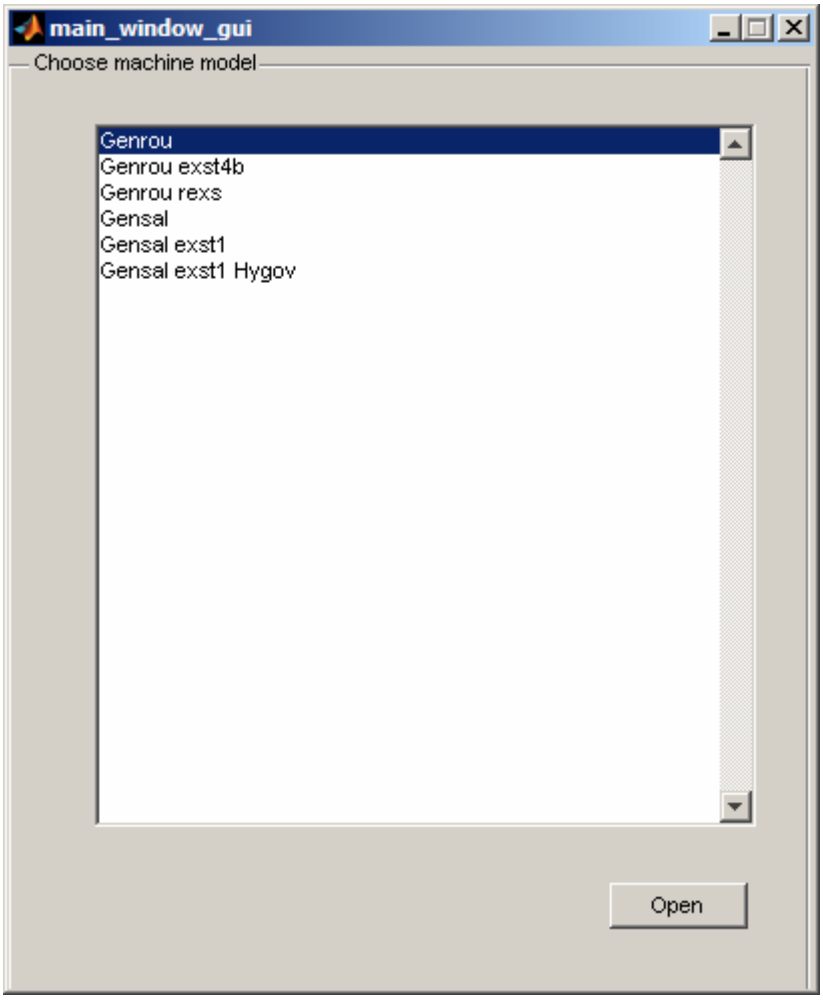


Figure 2.3 Opening Window

After selecting a model and pressing the Open button, the home screen will appear. This is shown in Figure 2.4.

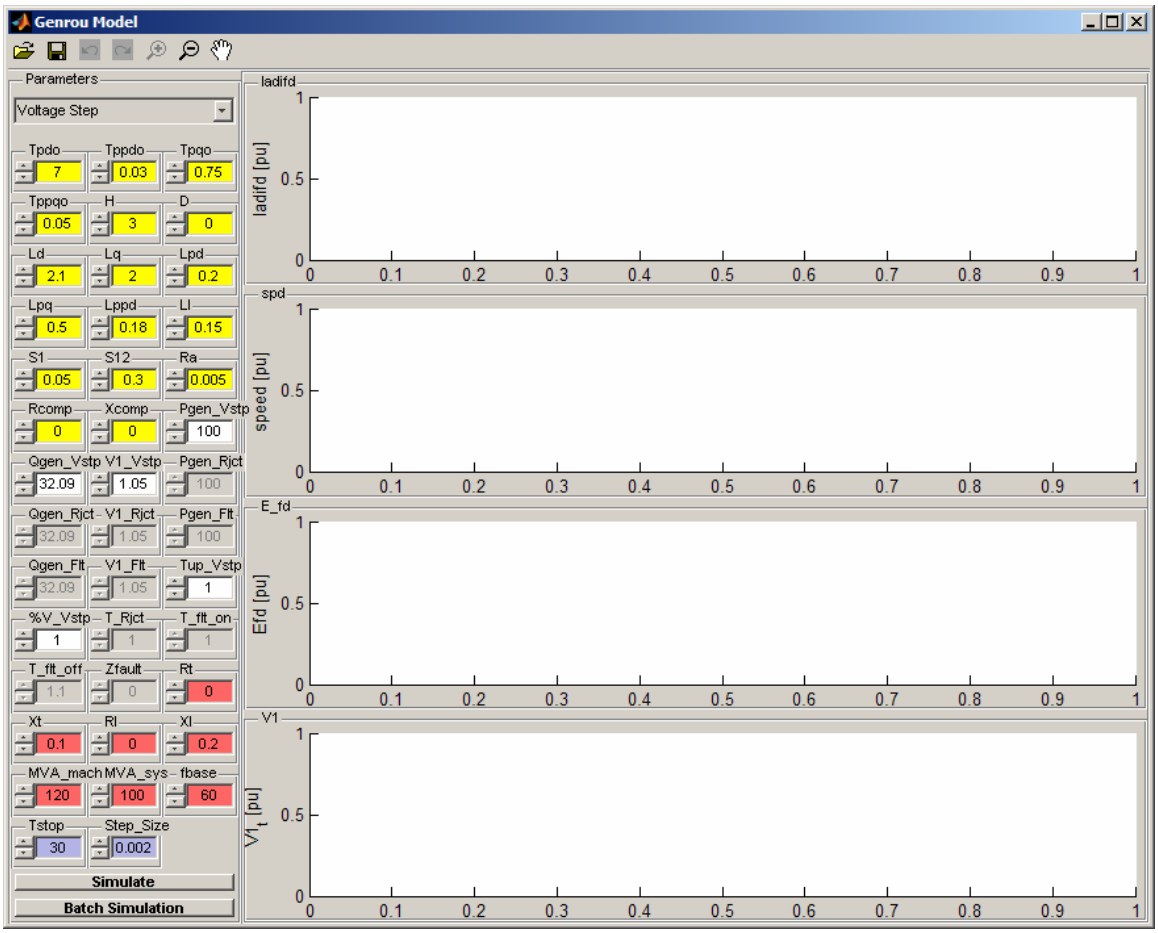


Figure 2.4 Home Screen

2.2 Adjusting Parameters

Parameters can be conviently adjusted using the slider bars that are provided on the left side of the home screen. A sample is shown in Figure 2.5. Each slider bar has its own default, minimum, and maximum value and maximum value. Pressing the up or down arrows increases the value in the edit box by 1 percent of the difference between the minimum and maximum value. It is also possible to enter a number in the edit box by hand. If this value is outside of the default minimum and maximum values, the appropriate limit will be reset to the value in the edit box.

Figure 2.5 Slider Bar

2.3 Selecting a Test

Tests can be selected from the pull down menu on the left side of the GUI. This is shown in Figure 2.6. Based on the entry selected, certain parameters will be uneditable. This is intended to prevent the user from accidentally adjusting the wrong parameter.

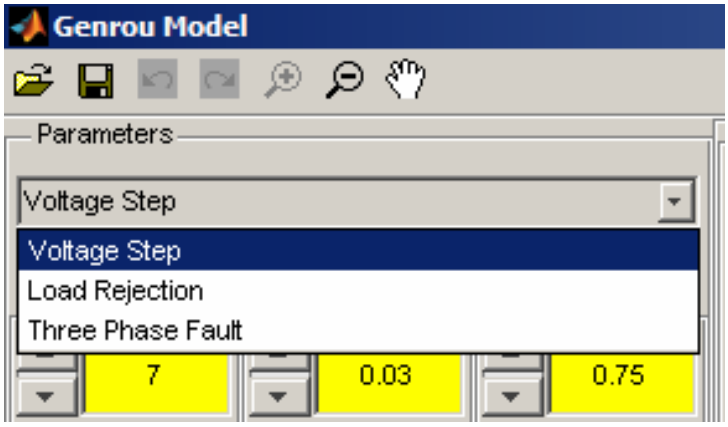


Figure 2.6 Test Pull Down Menu

2.4 Running Simulations

Standard simulations can be run using the "Simulate" button located in the lower left corner of the home screen. This is shown in Figure 2.7. Pressing this button will execute the simulation script, Simulink model, and plot the simulations results. During execution, a waitbar will appear to notify the user that a simulation is being executed.

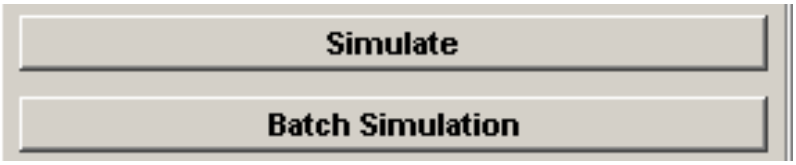


Figure 2.7 Simulate and Batch Simulate Buttons

2.5 Running Batch Simulations

Batch simulations can be run by pressing the "Batch Simulation" button located in the lower left corner of the home screen. This is shown in Figure 2.7. Pressing this button will make the Batch Simulation window appear. This window is shown in Figure 2.8.

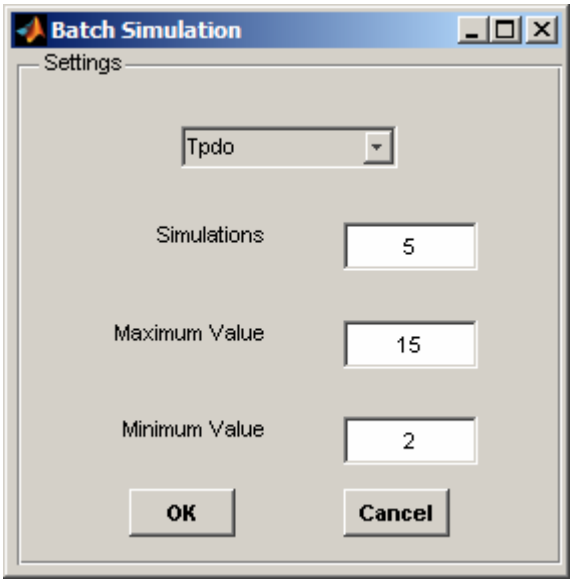


Figure 2.8 Batch Simulation Window

Batch simulation allows the user to execute several simulations at one time. The user can choose one parameter, the minimum logical value for this parameter, the maximum and the number of simulations that he wishes to perform. The program will run the number of simulations that the user selects with the selected parameter being slightly different each time.

The parameter to be varied can be selected using the pulldown menu located at the top of the GUI. The value in the "Simulations" box determines the number of simulations that will be run. The "Minimum Value"and "Maximum Value" boxes determine the values between which the program iterates.

2.6 Loading Test Data

Test data can be loaded by pressing the open button on the toolbar that appears across the top of the home window. The standard Windows Open dialog box will appear. This is shown in Figure 2.9. In the Files of Type menu at the bottom of the window, select Import Excel Test Data. Browse to the relevant file, select it, and press the open button. The data will be plotted. The test data must be formatted in the manner specified in 3.1.4.

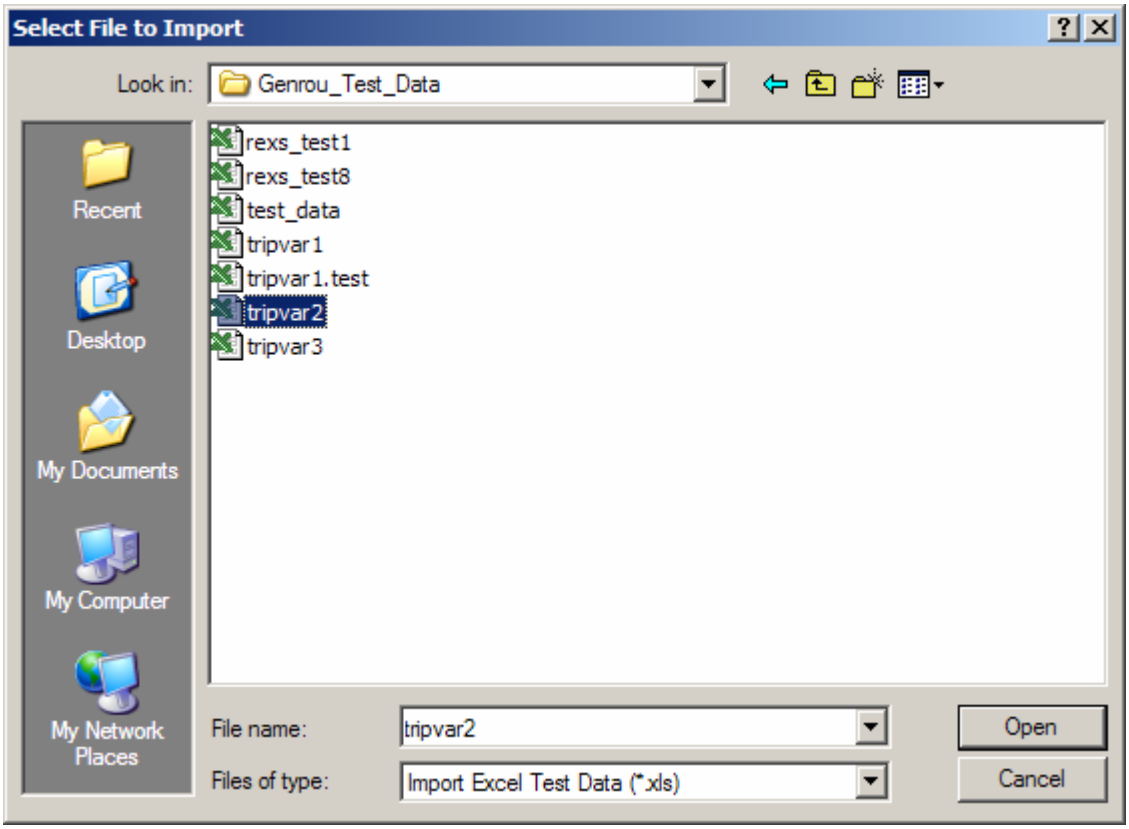


Figure 2.9 Loading Test Data

2.7 Saving and Loading Parameters

The values of the edit boxes can be saved and reimported during a subsequent session. To save the parameters, click the save button on the toolbar that appears across the top of the home screen. The standard Windows Save As dialog box will appear. This is shown in Figure 2.10. Select Save Paramter Setting from the Files of Type menu at the bottom of the window. Browse to the location where the files are to be saved and enter a name. Press the Save button. The parameter values will be saved in a .mat format.

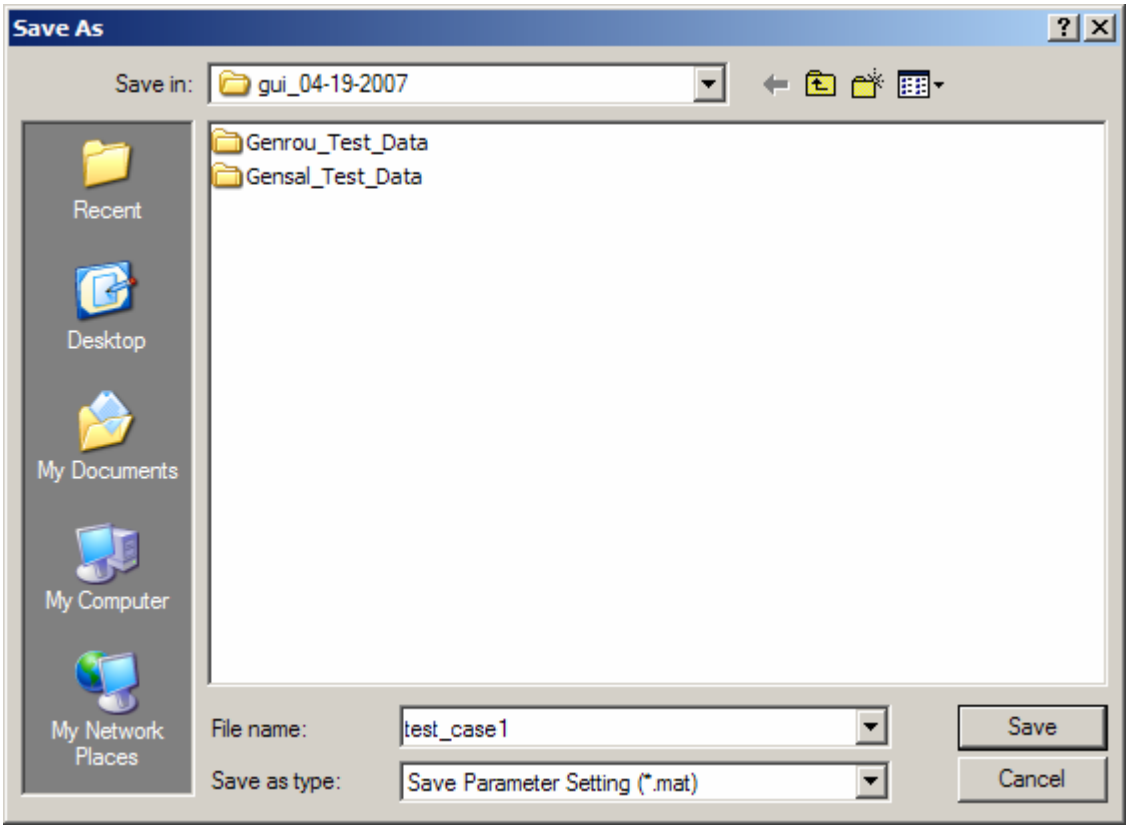


Figure 2.10 Saving Parameters

To open saved parameters from a previous session, press the Open button from the toolbar. The standard Windows save as box will appear. This is shown in Figure 2.11. Select Load Parameter Setting from the Files of Type menu. Browse to the folder containing the saved data, select the file, and press the Open button. The edit box values and slider bar position will be changed accordingly.

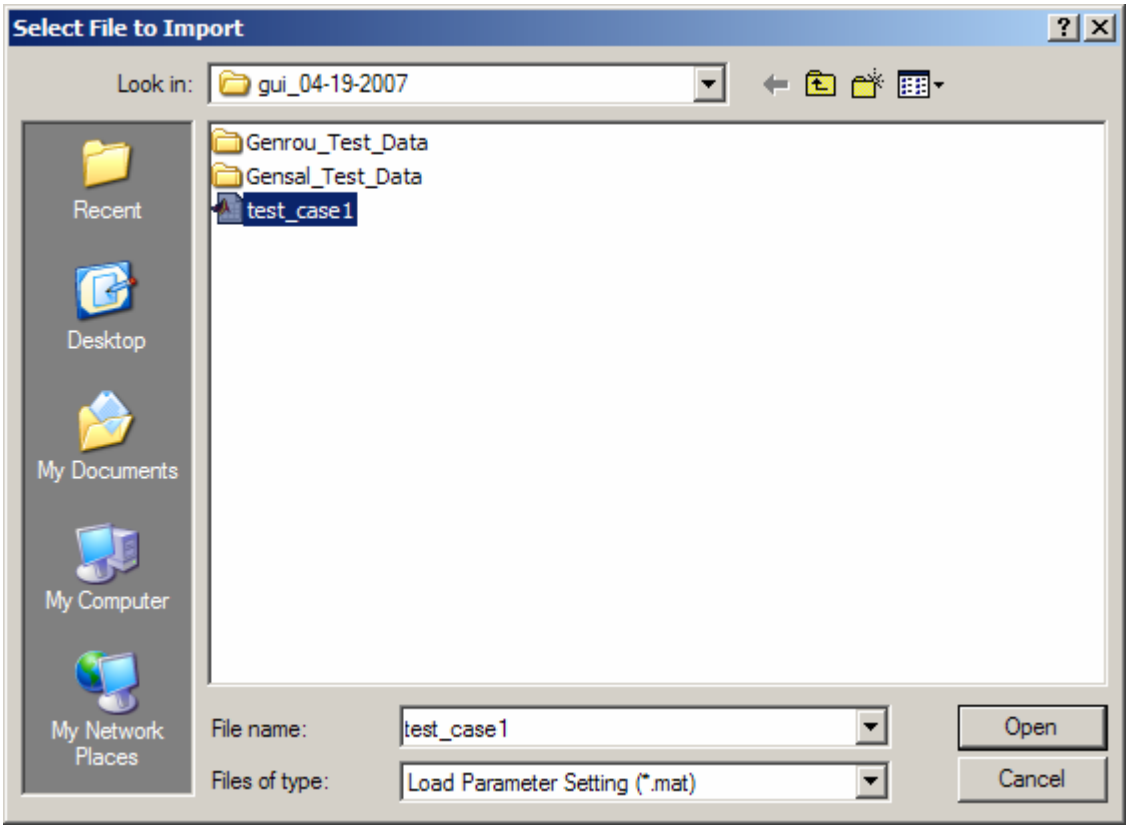


Figure 2.11 Opening Saved Parameter Settings

2.8 Saving Graphs and Exporting Simulation Data

The graphs and simulation data can also be exported. The graphs can be saved in jpeg format. To do this press the save button on the toolbar. The standard Windows Save As dialog box will appear. This is shown in Figure 2.12. Select Save Graphs from the Save as Type menu. Browse to the location where the graphs are to be saved. Type a file name and press the Save button. The graphs will be saved seperatly with the variable's workspace name appended to the filename that was entered.

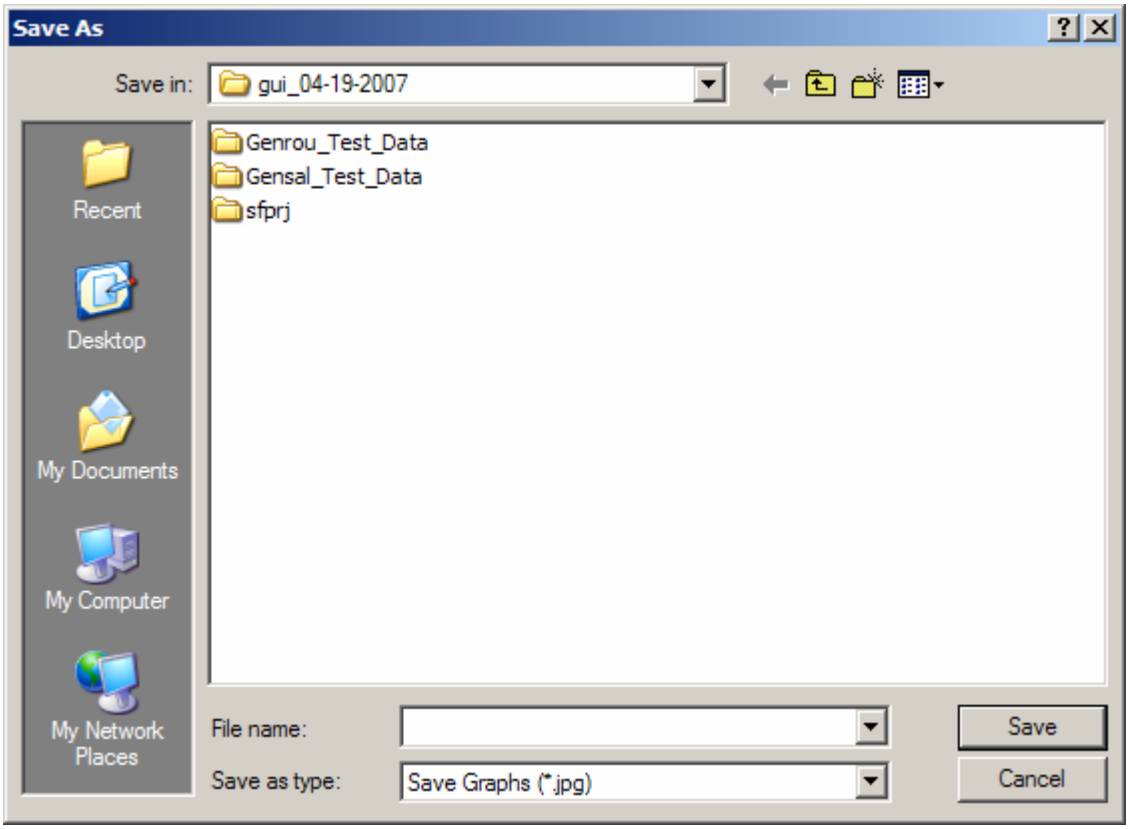


Figure 2.12 Saving Graphs

The simulation data can also be exported to an Excel file of the same format as the test data. This can be done by pressing the Save button on the toolbar. The standard Windows Save As dialog will appear. This is shown in Figure 2.13. Select "Save Simulation Data as Spreadsheet" from the Save as Type Menu. Brows to the location where the file is to be saved, enter a filename, and press the save button. The simulation data will be saved as an Excel spreadsheet. If the simulation time is particularly long, or the step size particularly small, the file size may be quite large. Typically, 30 seconds of simulation data requires approximately 1 MB of disk space.

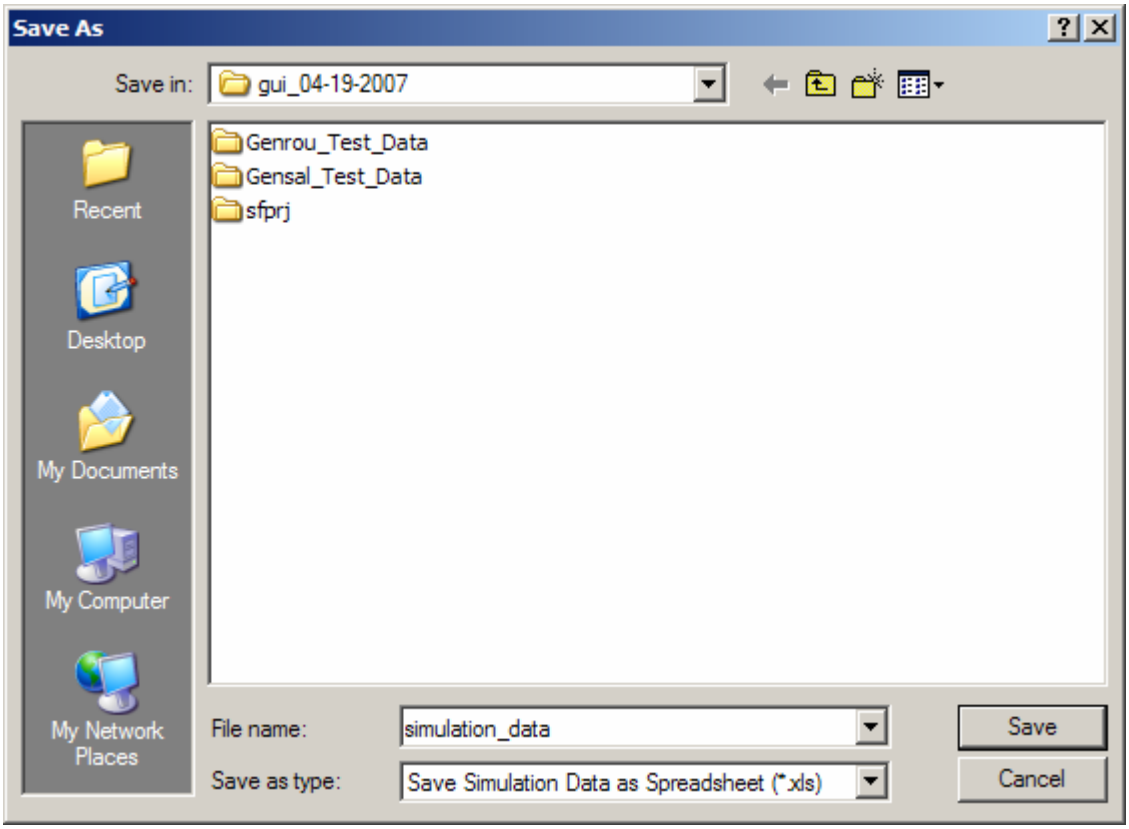


Figure 2.13 Exporting Simulation Data

3 Program Structure

This section is intended to provide the reader with an in-depth background in the program's structure and design. Complete source code appears on the accompanying CD.

3.1 Design Overview

The software was developed in the Matlab programming language and was designed for maximum flexibility. As a result of the modular design, the structure can be broken into several independent components. An overview of each of these components appears in Section 3.1 with a more detailed discussion of each in Sections 3.2 through 3.4.

The Matlab Graphical User Interface Development Environment (GUIDE) toolbox was used to generate the base code for the three main GUI components. Code generated using GUIDE contains a main function that executes the create function and processes the user inputs. A callback function is provided for each object (button, drop down menu, list box, edit box, slider bar, etc).

The layout function creates the GUI from standard Matlab components. A create function is also provided for each object. The callback functions allow the programmer to create code that will execute each time that a button is pressed, text is selected, or information entered. The callback functions allow for the programmer to create code that will execute when an object is created. The create functions were not used for this project.

3.1.1 Program Components

The program can be broken down into three basic components, the graphical user interface, the Simulink models, and the simulation scripts that connect them. The Matlab workspace serves as a swap memory of sorts. In virtually every location where one subprocess interfaces with another, variables are stored in the Matlab workspace by one process and called by another. This greatly simplifies the calling of functions as variables do not need to be explicitly passed. The simplified flow of information between the basic program components is shown in Figure 3.1.

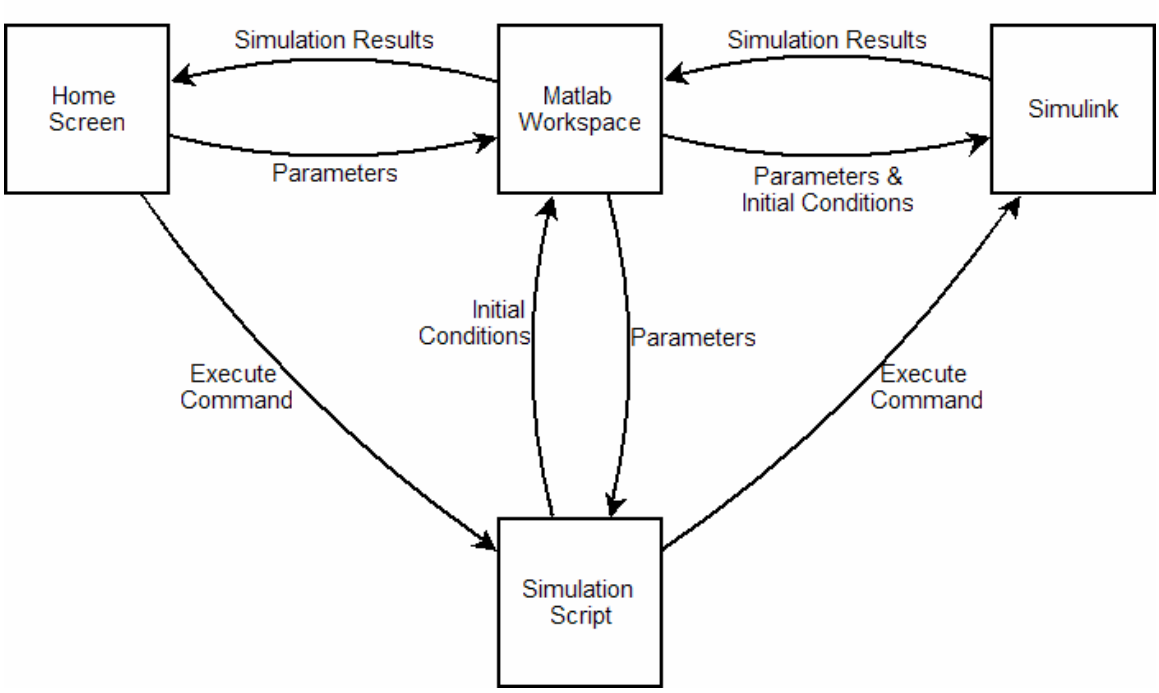


Figure 3.1 Simplified Flow of Information

3.1.1.1 Basic Algorithm

The basic algorithm is shown in Figure 3.2. After the initial program execution, the opening window appears. The user selects a model and presses OK. The home screen appears and the user imports test data and chooses to either batch simulate (run several simulations at once with slight adjustments to one parameter) or to edit parameters himself and simulate. The results are plotted with the test data and the user compares the results. If they are satisfactory, he exits the program, if they are not, he can choose to edit parameters or run more batch simulations. A more detailed version of this flowchart appears in Appendix A.

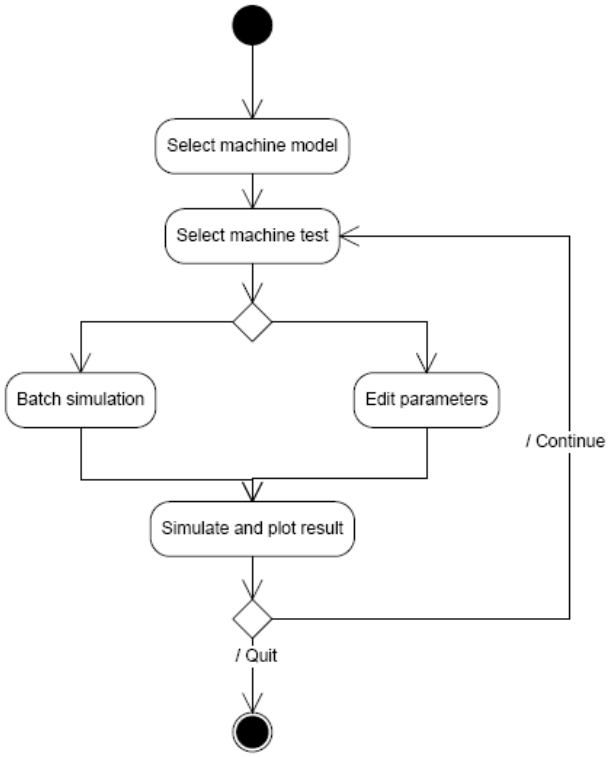


Figure 3.2 Simplified Flow Chart

3.1.1.2 Graphical User Interface

The graphical user interface is intended to provide the user with an easy means of entering parameters and viewing selected simulation results. It also provides several features such as the ability to undo or redo certain actions and import or export data that make it much more user-friendly. It can be broken into three basic components; the opening window (main_window.m), the home window (GUI.m), and the batch simulation window (batch_simulation.m).

The basic purpose of the graphical user interface is to collect parameters from the user, store them in the Matlab workspace, execute the simulation script, collect the arrays of simulation data, and plot them.

3.1.1.3 Simulink Models

The Simulink models are block diagram representations of the state space equations necessary for time domain simulations. It is very important that all constants be entered in as variables to ensure that they can be easily changed and that they will be changeable from the graphical user interface. Selected parameters are stored as arrays in the Matlab workspace.

The standard practice has been to use embedded Matlab functions for the algebraic equations corresponding to the electrical network and loads. It is very important that every integral have an initial condition defined. It is not necessary to use Simulink models. Instead, a state space model could be formulated and one of the time domain differential equation solvers could be used to solve the system.

3.1.1.4 Simulation Scripts

The simulation scripts are Matlab m-files that contain the equations necessary to calculate the initial conditions. After all of the initial conditions have been calculated, the Simulink model is executed.

3.1.2 The Matlab Workspace

The Matlab Workspace serves as a swap memory or information repository. Any information that needs to be shared between subprocesses is sent to the base Matlab workspace and then read in by the next process. This is intended to simplify function calling.

3.1.3 Setting Files

Setting files are Matlab scripts that create data structures in the Matlab workspace. They are intended to store default data needed to properly initialize the opening window without requiring the user to enter it manually each time the program executes. The main window setting file (main_window_setting_file.m) stores a list of the models in the library and the names of their respective setting files.

The several GUI setting files are specific to each model. They contain the information necessary to initialize the home screen including the name of each parameter in the Matlab workspace, the name that is to be displayed on the window, the minimum value of each slider bar, in addition to the maximum and default values. The GUI setting files also contain the workspace and display names for each of the values that are plotted and the names of each test, or simulation case, that the model can execute. Each model must have its own setting file. While creating setting files can be tedious, this method does allow the user to add models to the library without modifying the base graphical user interface code or creating a newly coded graphical user interface.

3.1.4 Test Data

The program allows data to be plotted from Microsoft Excel spreadsheets. This data must be saved in the .xls format and shall be arranged according to Table 3.1. It is important that the first column correspond to time (in seconds) and the remaining columns correspond to the outputs. There must be one and only one column for each output. If no data is available, then that column should be left as zeros, but never blank. The same format is used for exporting simulation data. A sample of test data appears in Appendix B.

Table 3.1 Sample Test Data Format

Time	Output #1	Output #2	Output #3	Output #4
0	0.1	0.2	0.4	0.8
1	0.2	0.4	0.6	1.6
2	0.3	0.6	0.8	2.4
3	0.4	0.8	1.2	3.2

3.1.5 Interaction Between Components and Flow of Information

The flow of information between subprocesses is shown in detail in Figure 3.3.

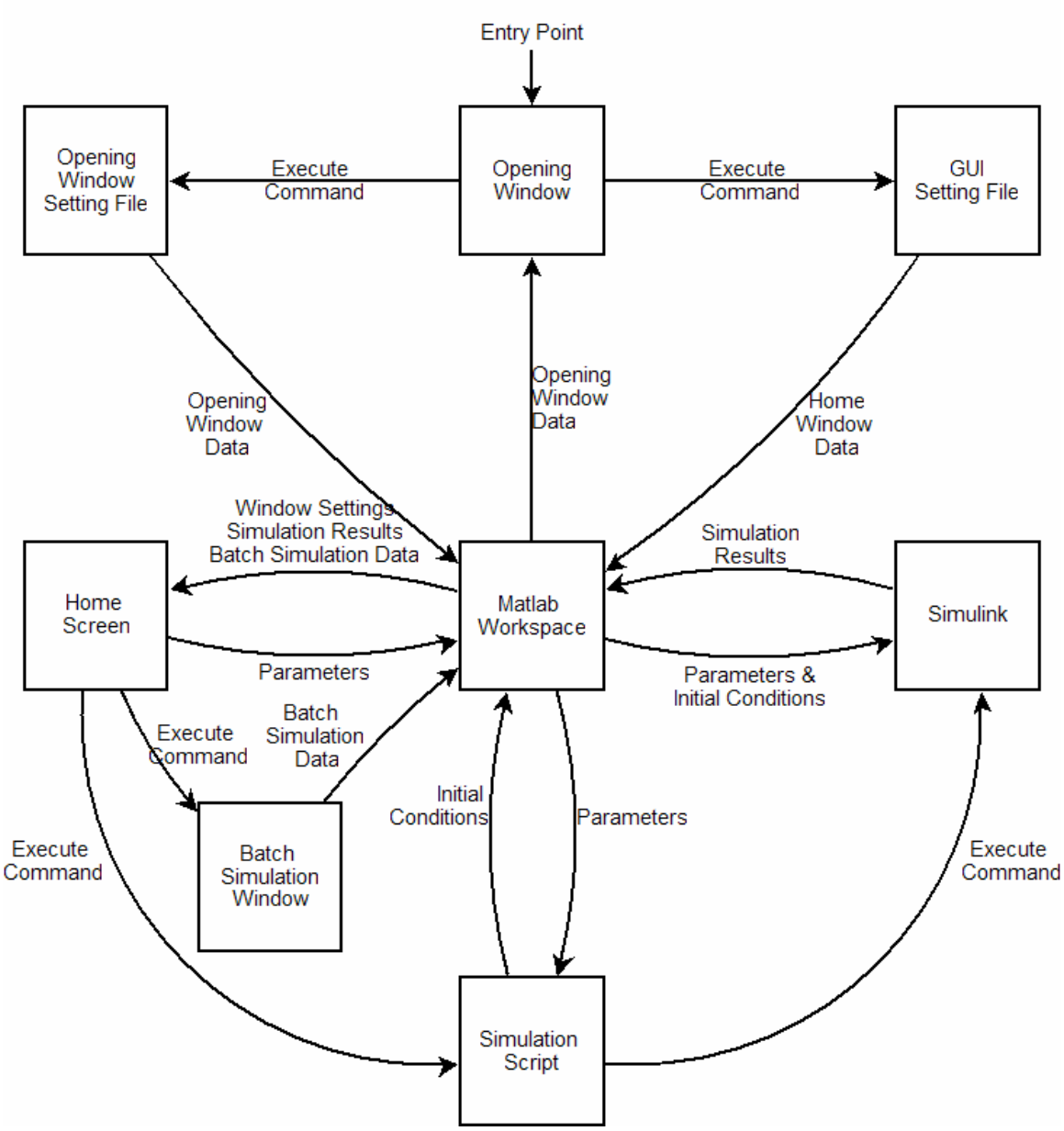


Figure 3.3 Detailed Flow of Information

As one can see, the Matlab workspace serves as the central information storage point. All data that is shared among processes is entered into the Matlab workspace.

3.2 Graphical User Interface

The graphical user interface can be broken into three components; the opening window (main_window.m), home window (GUI.m), and the batch simulation window (batch_simulation.m). Each of these components is described in detail in Sections 3.2.2 through 3.2.4. A discussion on the data structures that store all of the information necessary appears in Section 3.2.1. Complete source code appears on the accompanying CD.

3.2.1 Data Structures

Several data structures are used throughout the program, a summary of these appears in Table 3.2. The model_setting data structure is used by the opening window. There is one data structure for the entire library. The parameter_setting data structure contains the information needed for the parameters panel of the home screen. There is one parameter_setting structure for each model. The output_setting structure contains the information necessary for the output panel of the home screen. There is one output_setting for each model. The tests_setting structure is again model specific and contains the information necessary for the test selection menu on the home screen.

Table 3.2 Data Structures and their Fields

Structure	Purpose	Field	Purpose
model_setting	Stores the data needed by the opening window; the name of each model in the library and the setting file associated with that model. There is one structure for the entire library and one entry for each model. Found in main window setting file.	model_name	String value of the mode's name as it should be displayed on the home window.
		setting_file_name	String value of the setting file associated with that particular model.
parameter_setting	Stores the data that is needed for the parameters panel on the home window. This information is also used by the batch simulation window. There is one structure for each model and one entry for each parameter. Found in GUI setting file.	workspace_name	String containing the name of the parameter as it will appear in the workspace and will be used in the simulation script and Simulink model.
		min_value	Double containing the minimum parameter value.
		max_value	Double containing the maximum parameter value.
		default_value	Double containing the default parameter value.
		previous_value	Double containing the previous parameter value. Used for undo/redo functionality.
		current_value	Double containing the parameters current value.
		display_name	String containing the name of the parameter as it will appear on the parameters panel.
		description	Not used on current versions.
		color	A three double array that determines the color of the edit box.
		slider_panel	Not used on current versions.
		editability	An integer that determines for which tests the parameter is active. If this is set to 0 the parameter is always editable, if it is set to a number greater than 0, it will only be editable if the test pulldown menu is set to that position.

Table 3.2 Continued

Structure	Purpose	Field	Purpose
output_setting	Stores the data that is needed for the ouput panel on the home window. There is one structure for each model and one entry for each output. Found in the GUI setting file.	workspace_name	String containing the name of the variable as it appears in the Simulink block diagram and workspace.
		start_time	Not used on current versions.
		end_time	Not used on current versions.
		display_name	String containing the name that is displayed on the graph's Y-
		test_data	Double array containing the data imported from the Excel spreadsheets.
		simulation_data	Double array containing the simulation data.
		old_simulation_data	Double array containing the data from the previous simulation.
		test_time	Double array containing the time from the imported Excel data.
tests_setting	Stores the strings that are needed for the test selection menu on the parameter panel of the home window. Found in the GUI setting file.	test_name	String containing the name of the test as it is displayed in the test selection pulldown menu.

3.2.2 Opening Window

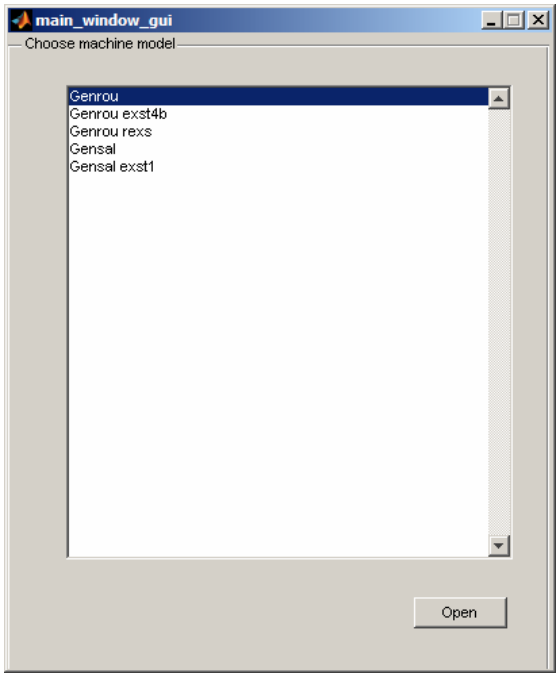


Figure 3.4 Opening Window

The opening window is shown in Figure 3.4 and serves as a user friendly interface for model selection. Upon execution, the main window setting file (main_window_setting_file.m) executes, placing the model_setting data structure into the Matlab workspace. The model_setting data structure contains the names of each model and the name of the corresponding gui setting file. After this executes, a screen similar to Figure 3.4 appears.

The program waits for the user to select a model and press the “Open” button. After the “Open” button is pressed, the program executes the GUI setting file that corresponds to the selected model executes, placing the parameter_setting, output_setting, and tests_setting data structures into the workspace. The GUI setting file is described in more detail in Section 3.2.3.2.

3.2.2.1 Structure

The base code for the main window was generated by the Matlab GUIDE toolbox. The create function contains code that executes the main window setting file, placing the model_setting structure in the Matlab workspace. This data is then read into a global variable that is used in the layout and “open” button callback functions. The callback function associated with the “Open” button was modified to execute the simulation script corresponding to the selected model. The main window can support any number of models.

3.2.2.2 Main Window Setting File

The main window setting file is a script file that creates a data structure named model_setting and places it in the Matlab workspace. This data structure contains two fields for each entry, one for the model’s name (model_name) and the other for the name of the GUI setting file that corresponds to the model.

3.2.3 Home Window

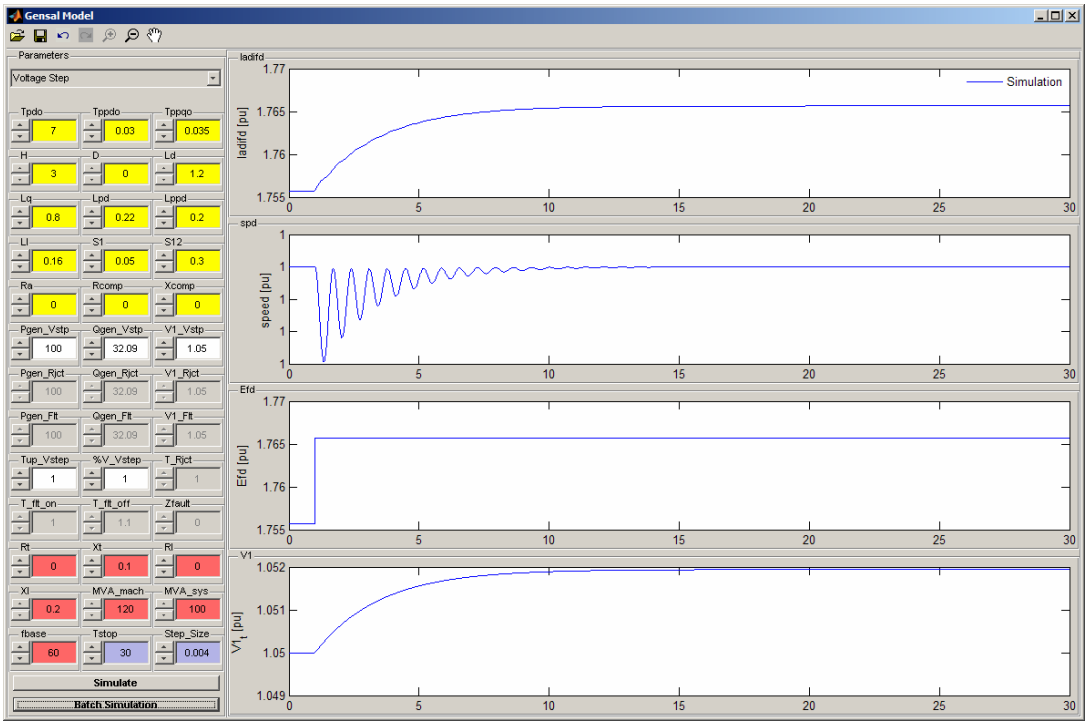


Figure 3.5 Home Window

The home window (GUI.m) is shown in Figure 3.5. This is the main interface that collects parameters from the user and displays the graphs of various parameters versus time. This window can, in general, be divided into three separate panels. The first is the toolbar that appears across the top portion of the display. This panel provides many features that are intended to make the software more user friendly. These are discussed in Table 3.3 in Section 3.2.3.1.1. The code necessary to implement these features is discussed in Section 3.2.3.1.2.

The panel on the left provides space for the simulation parameters while the panel on the right provides space for a graph of each output variable versus time. The amount of space allotted to each sub panel varies depending on the number of parameters displayed. For every 16 parameters, an additional column of parameters is added and an additional 6.8 percent of the display is allocated to parameters.

For each parameter, a sub panel consisting of an edit box and slider bar is provided. The edit box consumes approximately 70 percent of the sub panel while the slider bar consumes the remaining 30 percent. Under normal display resolutions, the slider bar is small enough that only the up and down (increase/decrease) arrows are visible. For each slider bar, there are default, minimum, maximum, and current values, which are found in the parameter_setting data structure. The initial values of these properties are contained in the GUI setting file and, with the exception of the default value, may change through out the session. If a value is entered into the edit box that is not between the

Other important features in the parameters panel are the simulate and batch simulate buttons and the drop down test selection menu. The simulate button places the parameters in the workspace, executes the simulation script, collects and plots the simulation results. The batch simulate button allows the user to run several simulations at once, with one variable being changed each time. This allows the user to visualize the effects of one parameter on the simulation results.

The test selection menu allows for several different events to be incorporated into one model and display. (The models built thus far have three different tests; a step change in reference voltage, a "load rejection" test in which the main breakers are opened, and a three phase fault.) Each time that the simulate button is pressed, the entry selected in the test menu is placed into the workspace as an integer, this is then collected by the simulation script and a switch statement determines which initial conditions to use and test to run. Because in real world testing situations, different tests may require different initial conditions, the graphical user interface can make the edit box and slider bar associated with certain parameters inactive based on the test selected in the drop down menu. This is intended to reduce the possibility of entering a parameter in the wrong edit box.

A sub panel is also provided for each output variable. Each sub panel has one plot box that consumes approximately 85 percent of the horizontal space and 92 percent of the vertical space. The sub panels are arranged in a stacked manner, with the horizontal (x) axis being much longer than the vertical (y) axis in any case where more than one graph is displayed.

3.2.3.1 Structure

A great deal of effort has been placed in making the entire graphical user interface as flexible and easily expandable as possible. The home screen has been created in such a way so as to in theory allow an infinite number parameters and plots, however, due to space restrictions, the user should attempt to limit the number of parameters to 96 and the plots to 6. The base code for the graphical user interface was created using GUIDE by building a basic window with the toolbar, parameters panel, and graph panel and then modifying the code to allow an infinite number of number of parameters and graphs.

Upon execution, the parameter_setting, model_setting, and tests_setting data structures are collected from the Matlab workspace and are saved as global variables. These are used throughout the program. After the main window appears the interface waits for user commands. After the simulate button is pressed, each parameter is placed in the Matlab workspace as a double variable. An integer corresponding to the selected test is placed in the workspace. The simulation script is executed, after this, the simulation data is collected from the Matlab workspace and plotted. Because the exact number of parameters or outputs is not fixed, loops were used. A wait bar (see Figure 3.6) is provided to remind the user that the simulation is in process. To ensure that the wait bar remains on top of all other Matlab windows, the window should be modal.

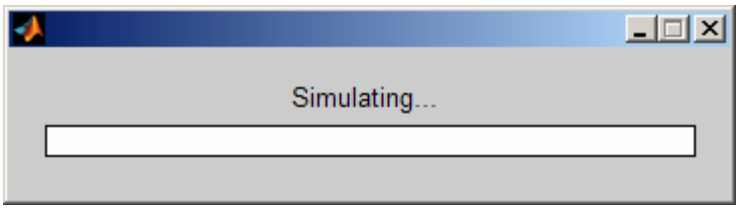


Figure 3.6 Wait bar

3.2.3.1.1 Features

Several user friendly features have been added. A summary of these features and their functionality appears in Table 3.3.

Table 3.3 Product Requirements and Features

Feature	Required or Supplemental	Intended Functionality
Edit Box	Required	Provide the user with a means to quickly enter a specific value for a parameter.
Slider Bar	Required	Provide the user with an easy method to vary parameters. Each slider bar shall have a default maximum and minimum value. When the slider bar position is changed, the value in the edit box shall update. If a value is entered into the edit box that is outside of this range, the corresponding maximum or minimum should reset to the value in the edit box.
Interface with Simulink	Required	The user shall be able to execute Simulink models from the graphical user interface.
Graph Simulation Data	Required	Simulation data shall be plotted on figures in the graphical user interface.
Import Data from Excel and Display on Graphs	Required	The user shall be able to import time domain data stored in Microsoft Excel spreadsheets in a format specified by the project team and plot them on the same graphs as the simulation data.
Undo/Redo Actions	Required	The user shall be able to undo actions upto to previous simulation.
Save Current Session	Required	The user shall be able to save the position of each slider bar.
Load Previous Session	Required	The user shall be able to load the position of each slider bar from a previous session.
Zoom In and Out on Graphs	Required	The user shall be able to zoom in and out on all graphs.

Table 3.3 Continued.

Feature	Required or Supplemental	Intended Functionality
Handle Simulation of Different Tests	Required	The graphical user interface shall be able to handle models capable of simulating different events
Handle Multiple Models	Required	The graphical user interface shall be capable of handling a library of any number of models. The project team shall enter at least 5 models into this library.
Pan Graphs	Supplemental	The user should be able to pan graphs.
Save Graphs as Matlab Figures	Supplemental	The user should be able to save graphs as Matlab figures.
Export Simulation Data to Excel Spreadsheet	Supplemental	The user should be able to save simulation data as an Excel spreadsheet in a format that is the same as the imported data.
Batch Simulation	Supplemental	The user should be able to choose a single parameter, specify a minimum and maximum value, and any number of simulations and have the program iterate that many times between those two points and graph the simulation data.
Hold Previous Zoom Level	Supplemental	When test data has been imported, the Graph's zoom level should not change after the simulate button is pressed.
Graph Previous Simulation Data	Supplemental	The previous simulation data should appear as a light gray line to allow the user to judge progress in matching the test data.
Color Code for Edit Box	Supplemental	Color edit boxes to help user to visually group different types of parameters belonging to different subsystems.

3.2.3.1.2 Callback Functions

Callback functions are used to specify what actions should occur after a certain action is performed.

3.2.3.1.2.1 Slider Bar and Edit Box Callback Functions

The slider bars share a common callback function. (The edit boxes do as well.) This is possible because each slider bar and edit box has its own handle, a double identification number that is unique to each object. The remaining buttons have their own callback functions. The edit box callback function collects the new value from the edit box and changes the position of the slider bar. The slider bar's range is adjusted if

necessary. The slider bar call back function contains code that updates the value in the edit box and adjusts the position of the slider bar.

3.2.3.1.2.2 Test Selection Menu Callback Function

The test selection drop down menu call back function first deletes both the current and old simulation data so that the gray trace associated with the previous simulation will not appear when the simulation button is next pressed. Each parameter is then checked to see if its status should be changed from active to inactive or vice versa.

3.2.3.1.2.3 Simulate Button Callback Function

The simulate button callback function first makes the simulate button inactive and changes the text from "Simulate" to "Simulating…" Next a wait bar is created and each parameter is placed in the workspace. If this test has been simulated previously, the old simulation data is placed into the old_simulation_data field in the output_setting data structure and the simulation is executed. If there is a problem with the simulation, a catch statement will cause a message box displaying "Simulation error" to appear. This is shown in Figure 3.7. This prevents the program from crashing, but does not provide much insight into the source of the problem. If the simulation executes properly, the results are plotted and a legend appears in the upper right hand corner of the top plot box. A custom color scheme is defined to ensure that all of the plots are legible and that all colors are pleasing to the eye.

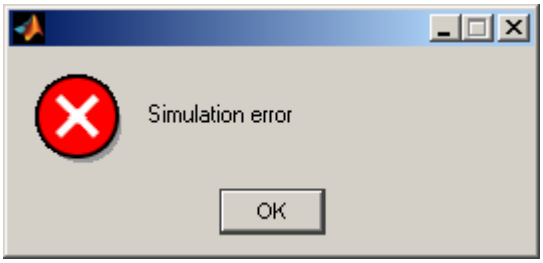


Figure 3.7 Simulation Error Message Box

3.2.3.1.2.4 Batch Simulate Button Callback Function

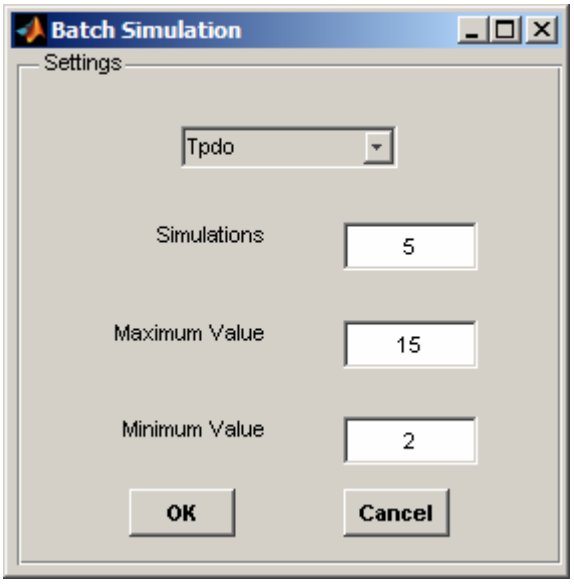


Figure 3.8 Batch Simulate Window

The batch simulate call back function starts by making the batch simulate button inactive and changing the text from "Batch Simulate" to "Simulating…" The batch simulation window appears and the program suspends execution until the user presses either the OK or cancel button. The batch simulation window appears in Figure 3.8. After this, the program resumes execution, if the cancel button was pressed, the program returns to the main function and does not simulate. If the OK button was pressed, a wait bar is displayed and the function collects the parameter, minimum value, maximum value, and number of simulations from the workspace. After this an array of parameter values for the parameter that will be varied is created and all of the parameters are placed in the workspace. After the simulation has completed, the data is plotted. The program repeats this for the desired number of simulations.

3.2.3.1.2.5 Open Button Callback Function

The open button callback function starts by opening the standard windows "Open File" window. This window is shown in Figure 3.9. The user has the option to either import test data from an Excel spreadsheet or load a saved case in the form of a Matlab .mat file.

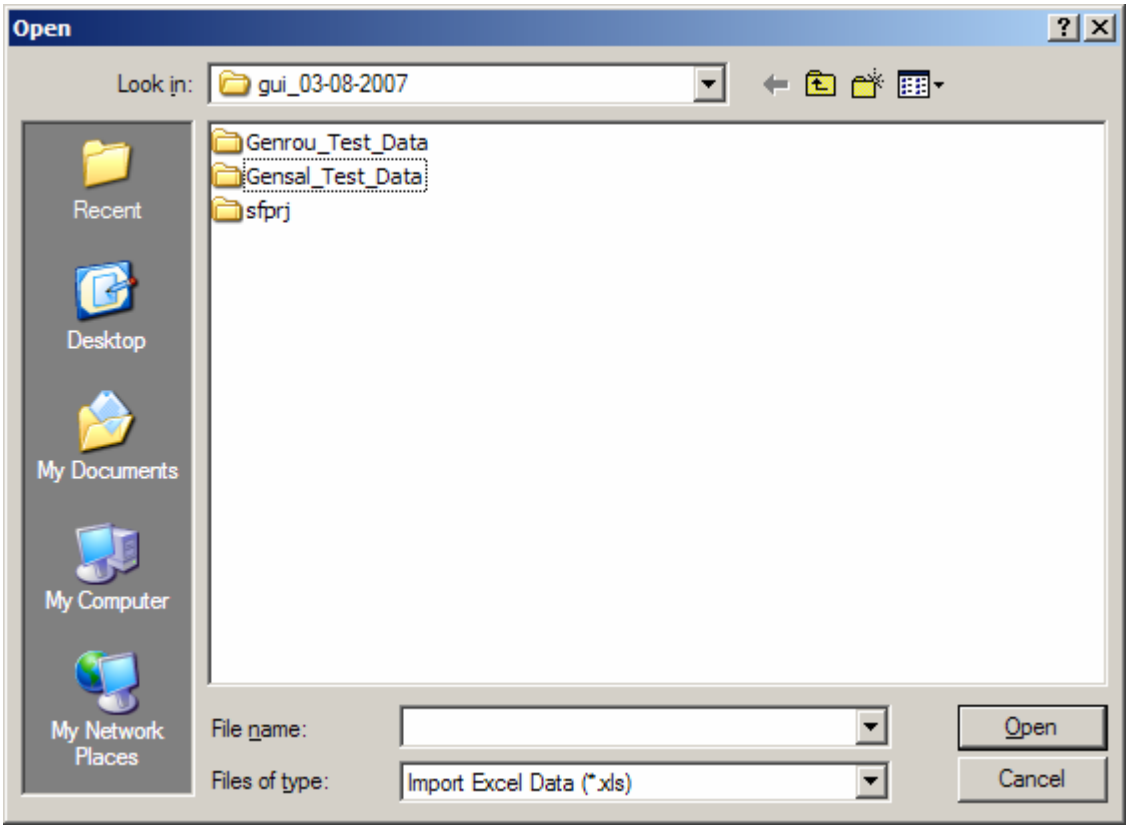


Figure 3.9 Open Window

After the user has selected a file, the program attempts to open it as an Excel file, if it succeeds, the data is plotted, if it fails, the program attempts to open it as a .mat save case. If this succeeds, each parameter is set to the value in the file, if this fails as well, an error message is displayed.

3.2.3.1.2.6 Save Button Callback Function

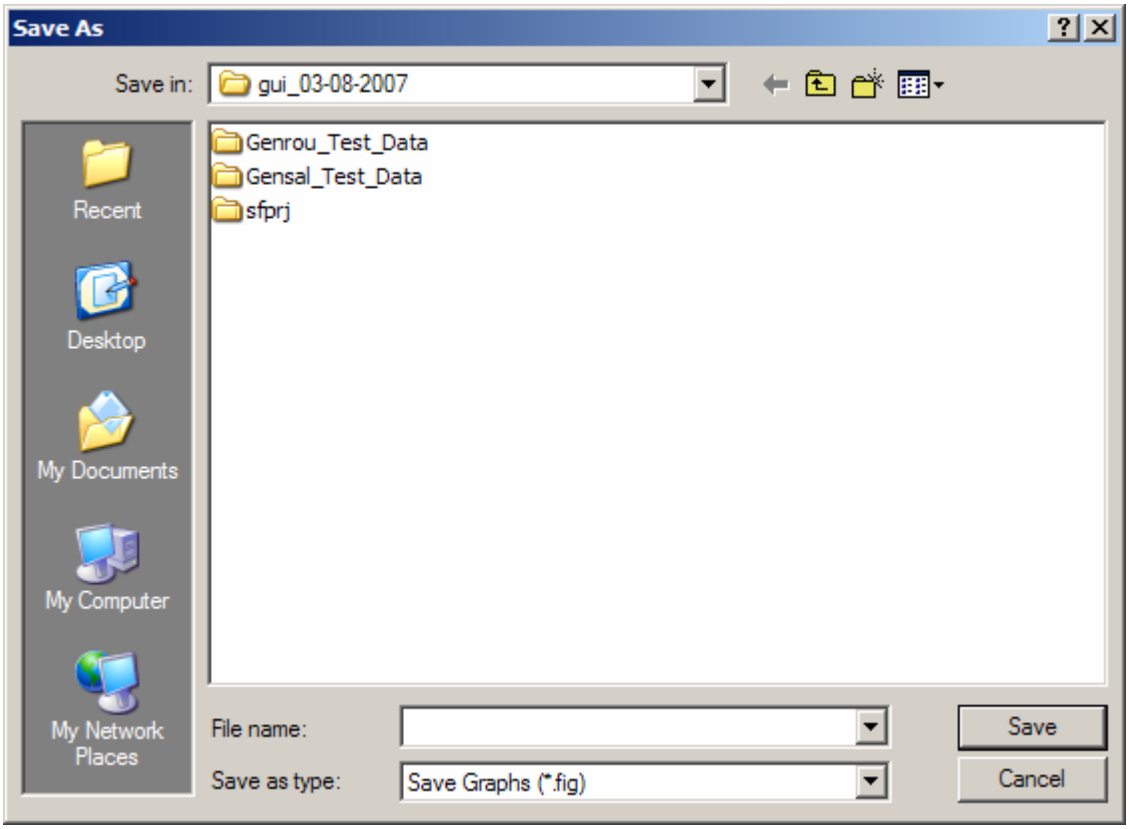


Figure 3.10 Save As Window

The save button callback function starts by opening the standard Windows Save As dialog box. This is shown in Figure 3.10. The user has the option of saving three different files. The first is to save the output plots as jpeg (.jpg) files. If this option is chosen, the program will save each graph individually with the workspace name of the output variable concatenated to the end of the filename. If the user elects to save the parameter data (save case) as a .mat file, the parameter_setting array is saved. If the user wishes to save the simulation data, the simulation data is saved to an Excel spreadsheet in the format in Section 3.1.4.

3.2.3.1.2.7 Undo/Redo Button Callback Functions

If the Undo toolbar button is pressed, the program changes the last modified parameter to its previous value and enables the redo button. If the redo button is pressed, the last undone parameter is changed to its pre-undo value. It should be noted that the undo functionality is only available after the simulate button has been pressed and can only undo changes up to the previous simulation.

3.2.3.1.2.8 Zoom In, Zoom Out, and Pan Button Callback Functions

The zoom in, zoom out, and pan callback functions are all very similar. Each one changes the zoom property of each graph to either zoom in, zoom out or pan, disables the button that was pressed, and enables the other two.

3.2.3.2 GUI Setting File

The GUI setting file is a Matlab script that creates three data structures. The first, parameter_setting, contains the data necessary for the slider bars and edit boxes. There is one entry in this data structure for each slider bar or edit box on the parameters panel. The next, output_setting, contains all of the information necessary for the graphs on the output panel. The last, test_setting, contains the information needed for the test selection menu. These data structures are described in detail in Table 3.2. Three additional string variables, simulin_file_name, simulation_file, and simulation_script, are also placed in the workspace. simulin_file_name contains the name of the Simulink block diagram. simulation_file contains the title given to the home window. simulation_script contains the name of the simuation script associated with that particular model. An example setting file is included in Appendix C.

3.2.4 Batch Simulation Window

The batch simulation window, shown in Figure 3.8 allows users to run several simulations at one time, varying one parameter each time. This is intended to allow the user to see the effects of different values of one parameter and to aid in the overall parameter selection process.

When the batch simulate button is pressed, the batch simulate window appears. A pull down menu allows the user to select which parameter will be varied. The maximum and minimum values correspond to the points between which the program will iterate. By default, these are set at the minimum and maximum slider bar values. A callback function ensures that when the position of the pull down menu changes, that the maximum and minimum values will change. The simulations edit box allows the user to set the number of times that the program will run. This number must be an integer greater than 1.

When the OK button is pressed five variables are passed to the Matlab workspace. parameter, is an integer corresponding to the parameter selected in the pull down menu. The maximum value, max, the minimum value, min, the number of simulations, simulations, and an exit flag cancel. If cancel is set to 1, because the cancel button was pressed, the home screen will not run the simulation, if the OK button is pressed, cancel will be set to 0 and the home screen will run the simulations.

3.3 Simulation Scripts

The simulation scripts are Matlab scripts that collect parameters from the workspace, determine which test to run, and initial conditions to use, calculates additional initial conditions, and executes the Simulink model.

Though these scripts are very flexible, the standard practice has been to use a switch statement that switches based on the test selected. The initial conditions corresponding to this test are chosen in this statement. In the lines that follow, more initial conditions are calculated using algebraic expressions. The last line executes the Simulink model. It is very important that the variables used in the simulation script exactly match the

variables used in the Simulink models and GUI setting files. An example has been included in Appendix E.

It should be noted that it is not necessary to use Simulink block diagrams. The simulation script can be used to build a state space model of the system being studied. Any one of the Matlab differential equation solvers can be used to perform the simulation.

3.4 Simulink Model

The Simulink models used for simulations are also very flexible. They can be models of any dynamic system and do not need to be from the power industry. The standard practice has been to use block diagrams for the generator windings, exciters, voltage regulators, turbines, and governors and imbedded Matlab code for the algebraic equations corresponding to the electrical network.

The simulation time and step size need to be adjustable via the home screen, thus the appropriate settings in the configuration parameters dialog box (Simulation -> Configuration Parameters) need to be changed to variables. Variables will be used in place of constants on all blocks in the algebraic equations in order to maximize flexibility. A sample Simulink block diagram appears in Appendix D.

4 Program Maintenance

This section is intended to serve as a guide and reference manual for product maintenance. It includes information examples on how to add models to the library and modify existing models.

4.1 Adding Models to Library

This section will discuss the process used to add models to the library. The process basically consists of creating the Simulink model and simulation script, creating the GUI setting file, and editing the Main Window setting file. These are described in more detail Sections 4.1.1 through 4.1.4. An example appears in Section 4.1.5. Before reading this section, the reader should study Table 3.2, a description of all of the data structures used in the program.

4.1.1 Compatible Simulink Models

A compatible Simulink model has several characteristics, the first is that all parameters must be entered in as variables. The name that it is used in the Simulink model will be referred to as the workspace name. This name should be the same name that is used in the "workspace_name" field of the parameter_setting data structure. The model must also have the simulation stop time set to Tstop and the fixed step size must be set to Step_Size. The solver type should be set to fixed-step. Standard practice has been to use the ODE-3 solver. The can be set in the Configuration Parameters dialog box. This can be found in the Simulink Simulation menu.

All data that the user wishes to plot should be connected to a "To Workspace" block. The variable name should be set to the same that appears in the "workspace_name" field of the "output_setting" data structure. The save format field should be set to array.

Initial conditions can be imported from the workspace using "constant" blocks. The "constant value" field should be set to the name as it appears in the simulation script. It is very important that every integral have an initial condition. A sample block diagram appears in Appendix C.

4.1.2 Compatible Simulation Scripts

Simulation scripts are files that calculate initial conditions and determine which test to simulate. These files are very flexible though the generally excepted form is to have the first few lines be a switch statement that determines which test to execute.

The variable to be switched is test_switch. This variable is an integer that is determined based on the position of the test pull down menu when the simulate button is pressed. The order that the tests appear in, and thus the value of test_switch that corresponds to a particular test is determined by its index in the test_setting menu. The generally excepted order is voltage step, load rejection and three phase fault. The generally excepted switch statement appears below and is applicable to all generator models.

```
switch test_switch
    case 1
        pgen = Pgen_Vstep;
        qgen = Qgen_Vstep;
        vm = V1_Vstep;
        vstep = .01*Vup_Vstep;
        tstep = Tup_Vstep;
    case 2
        pgen = Pgen_Ld_Reject;
        qgen = Qgen_Ld_Reject;
        vm = V1_Ld_Reject;
        ton = Treject_Ld_Reject;
    case 3
        pgen = Pgen_Flt;
        qgen = Qgen_Flt;
        vm = V1_Flt;
        ton = T_flt_on;
        toff = T_flt_off;
end
```

The last line executes the Simulink model using the “sim” command. The simulation scripts appear in Appendix I.

4.1.3 Creating GUI Setting File

The GUI setting file is a Matlab script that sets up the databases needed for the main graphical user interface. A summary of these data structures appears in Table 3.2 and a sample setting file appears in Appendix B. When adding models, it is usually quicker and easier to edit an existing setting file than it is to start a new one.

4.1.4 Editing Main Window Setting File

The main window setting file contains the data necessary to display all of the models in the opening screen and execute the correct simulation script. The current file appears below.

```
model_setting=struct(...
    'model_name',{...
    'Genrou',...
    'Genrou exst4b',...
    'Genrou rexs',...
    'Gensal',...
    'Gensal exst1',...
    'Gensal exst1 Hygov'
    },...
    'model_folder',{...
    %folder containing all the necessary files
    %it should be located inside the current directory
    ''...
    ''...
    ''...
    ''...
    ''...
```

```
            ''
            },...
            'setting_file_name',{...
            'genrou_setting_file',...
            'genrou_exst4b_setting_file',...
            'genrou_rexs_setting_file',...
            'gensal_setting_file',...
            'gensal_exst1_setting_file',...
            'gensal_exst1_hygov_setting_file',
            }...
        );
```

The 'model_name' field is the name of the model as it appears in the model list on the opening window. If a model is added the model's name should be added in quotation marks at the end of the list. The 'model_folder' field is no longer used, if a model is added, empty quotation marks should be added at the end of the list. The "setting_file_name" should be the name of the GUI setting file that corresponds to this model the should be added in quotation marks at the end of the list with out the ".m."

4.1.5 Example: Creation and Addition of Classical Machine vs. Infinite Bus

In order to illustrate the concepts laid out in Sections 4.1.1 through 4.1.4, the reader will be walked through an example of creating a Simulink model and simulation script that are compatible with the GUI and then adding them to the library. The example will be the classical machine against an infinite bus.

4.1.5.1 Preparation

The following data must be collected before beginning to create the model:

- A basic block diagram of the model must be prepared.
- Detailed equations to calculate initial conditions.
- Equations linking the block diagram to the rest of the network.
- A list of all tests that need to be built into the model and displayed on the GUI.
- A list of all parameters that need to be displayed on the graphical user interface. This information should include:
    - The name of each parameter.
    - A default value for each parameter.
    - A minimum value for each parameter.
    - A maximum value for each parameter.
- A list of all simulation results that need to be plotted.

The following data has been prepared for the classical machine against an infinite bus.

A block diagram of the classical model appears in Figure 4.1.

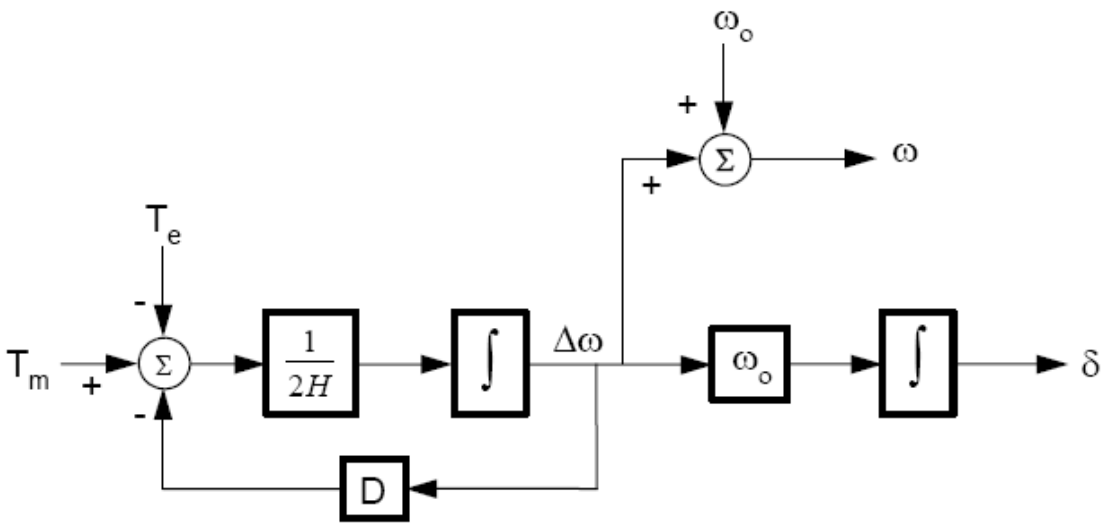


Figure 4.1 Block Diagram of Classical Model

It will be assumed that the user will supply the starting terminal voltage and real and reactive power generation. It will be assumed that the voltage angle at the machine terminals will be zero, the initial power angle and voltage angle at the infinite bus will be adjusted accordingly. The following equations can be used to calculate the initial conditions:

```
S = P1+j*Q1
I = conj(S/V1);
E=abs(V1+zgen*I);
deltao=angle(V1+zgen*I);
Vinf= V1-(ztran+zline)*I;
```

The model needs to simulate load rejections and three phase fault, standard practice is to simulate a voltage step as well. This is not logical for the classical model. The equations to do this appear in Section 4.1.5.3. The basic technique is to develop admittance matrices for the three scenarios (pre-fault, faulted, load rejected) networks and reduce them using the Kron reduction technique.

The following equations can be used to connect the block diagram to the infinite bus:

```
I=Ybus*[E(cos(delta)+j*sin(delta));Vinf];
Pe=real(E1*conj(I(1,1)));
Te=Pe*w;
V1=EI(1,1)*(ra+j*xpd);
```

A lot of data besides the generator parameters need to be displayed on the GUI. These include the simulation stop time and step size, the initial conditions for each test, the system power and frequency bases, the disturbance time for each test, and the impedances of network components such as the transmission line and transformer. The data needed to create the GUI setting file appears in Table 4.1.

Table 4.1 GUI Parameters

Workspace Name	Minimum	Default	Maximum	Display Name
h	1	3	7	H
d	0	1	2	D
ra	0	0.05	0.05	Ra
xpd	0.1	0.2	0.5	Xpd
pgen_fault	0	100	500	P_fault
qgen_fault	-500	30	500	Q_fault
v1_fault	0	1	1.05	V1_fault
t_fault_on	0	1	10	t_flt_on
t_fault_off	0	1.1	10	t_flt_off
zfault	0	0	10	Zfault
pgen_reject	0	100	500	P_rjct
qgen_reject	-500	30	500	Q_rjct
v1_reject	0	1	1.05	V1_rjct
t_reject	0	1	10	t_reject
mva_base	1	100	500	S_Base
fbase	50	60	60	fbase
rl	0	0.2	0.5	Rl
xl	0.001	0.2	1	Xl
rt	0	0.1	0.5	Rt
xt	0.001	0.5	1	Xt
Tstop	1	30	60	Tstop
Step_size	0.0001	0.005	0.01	Step_size

Standard practice is to plot the terminal voltage, field voltage, field current, and speed. Because the classical model does not have field voltage or current, we will plot terminal voltage, rotor angle, speed, and real power output.

4.1.5.2 Creation of Simulink Model

This section will outline the creation of the Simulink block diagram. The first step in creating the model is to enter the basic block diagram into Simulink. This is shown in Figure 4.2. Using to and from blocks can clean up the block diagram and make it more apparent, what is happening. The bottom set of blocks create a complex number that will be used later to determine the current that is supplied. It can be difficult to create complex numbers in imbedded Matlab functions, the standard practice is to combine the magnitude and angle outside of the imbedded Matlab function.

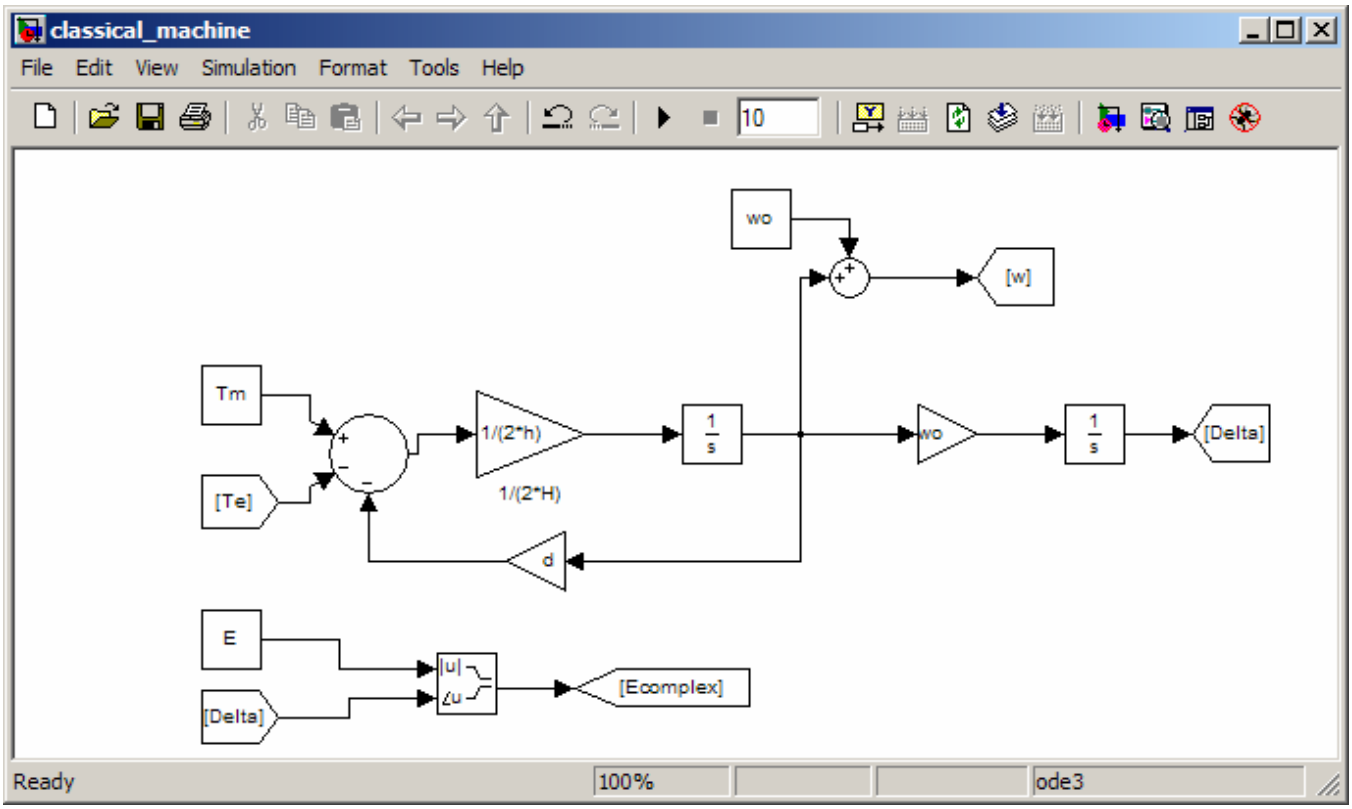


Figure 4.2 Basic Block Diagram as Simulink Model

It is very important that the right most integral's initial condition be set to "deltao." This is shown in Figure 4.3. Normally all integrals need an initial condition, the output of the right initial condition corresponds to the speed deviation, this initial condition is zero because it is assumed that the machine is starting from its base speed.

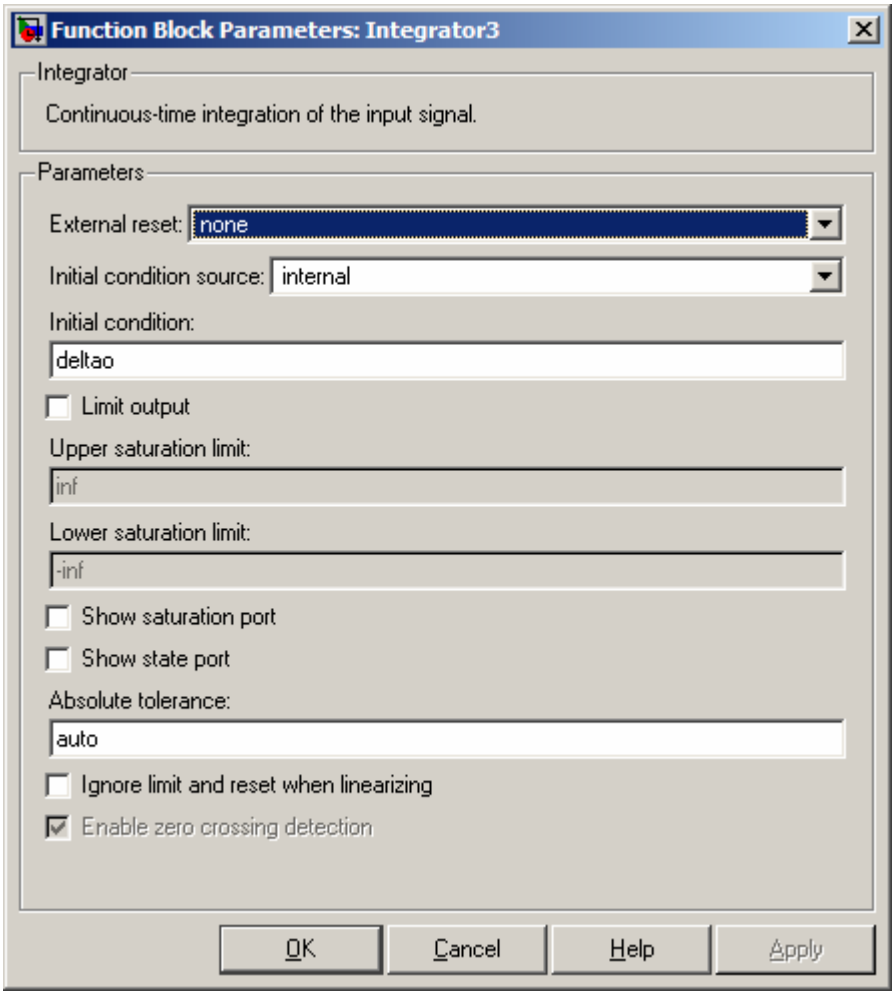


Figure 4.3 Integral Initial Condition

The next step is to add an imbedded Matlab function that connects the generator to the network. This function will use some of the equations gathered in Section 4.1.5.1. The complete text of the embedded Matlab function appears below.

```
function [Te,V1,Pgen] =
network(E,w,Vinf,Time,Ton,Toff,Ypre,Ydist,zgen,fbase)

%Calculate currents
if (Time<Ton)||(Time>=Toff)
    I=Ypre*[E;Vinf];
else
    I=Ydist*[E;Vinf];
end

%Find voltage at generator terminals
Vt=E-zgen*I(1,1);

%Find the real power injection from the generator
Pgen=real(Vt*conj(I(1,1)));
```

```
%perunitize speed
wpu=w/(2*pi*fbase);

%Find the electrical torque supplied by the generator
Te=Pgen/wpu;

V1=abs(Vt);
```

A screen shot of the imbedded Matlab function appears in Figure 4.4.

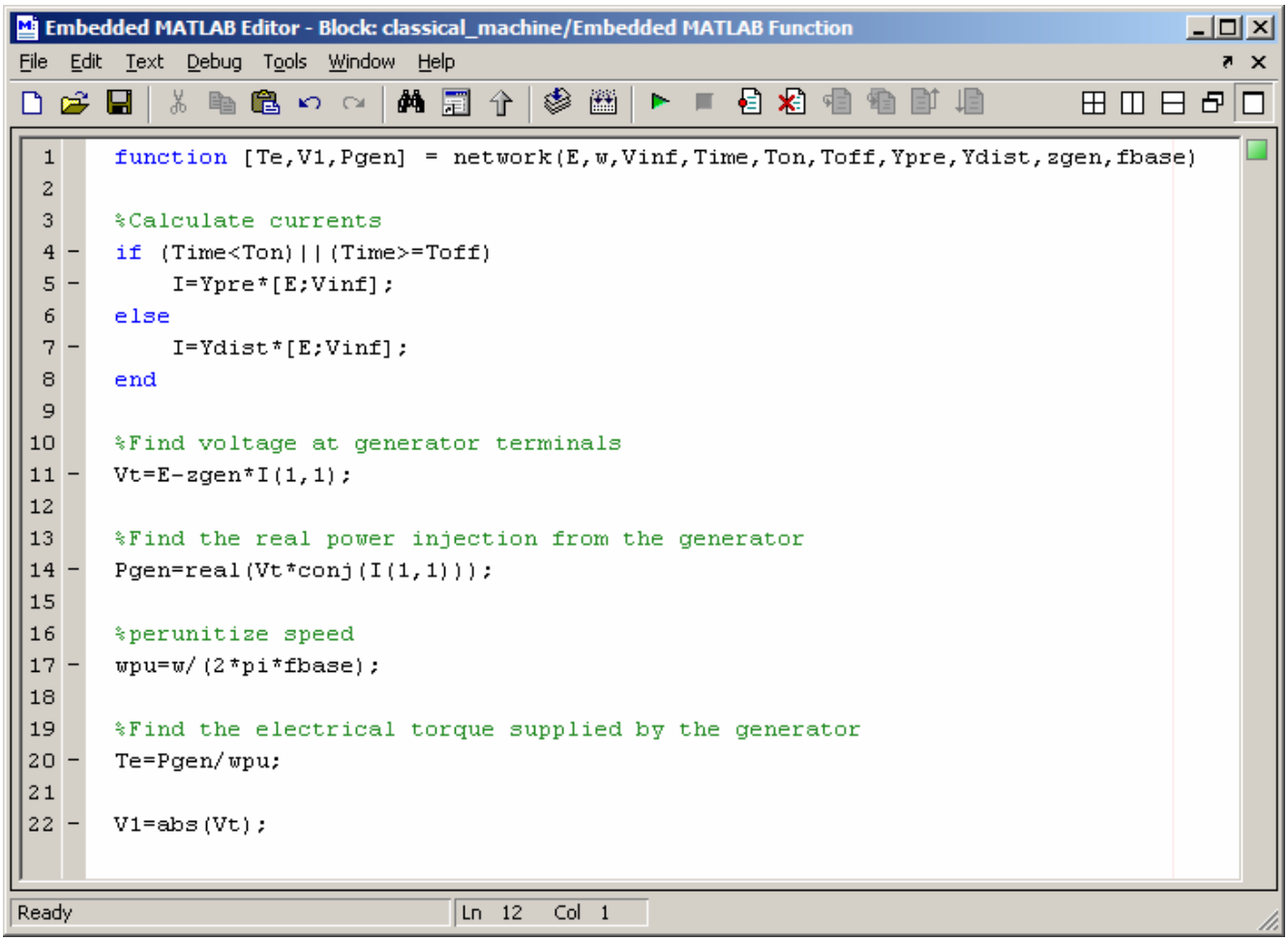


Figure 4.4 Imbedded Matlab Function

This should be connected to the rest of the block diagram as shown in Figure 4.5. "From" blocks should be used for Ecomplex and w. For the constants, use a "constant" block and change the value to the variable name as it will appear in the Matlab workspace. The "clock" block should be used to import the time into the embedded Matlab function. A "to" block should be used to connect the electrical torque with the rest of the network.

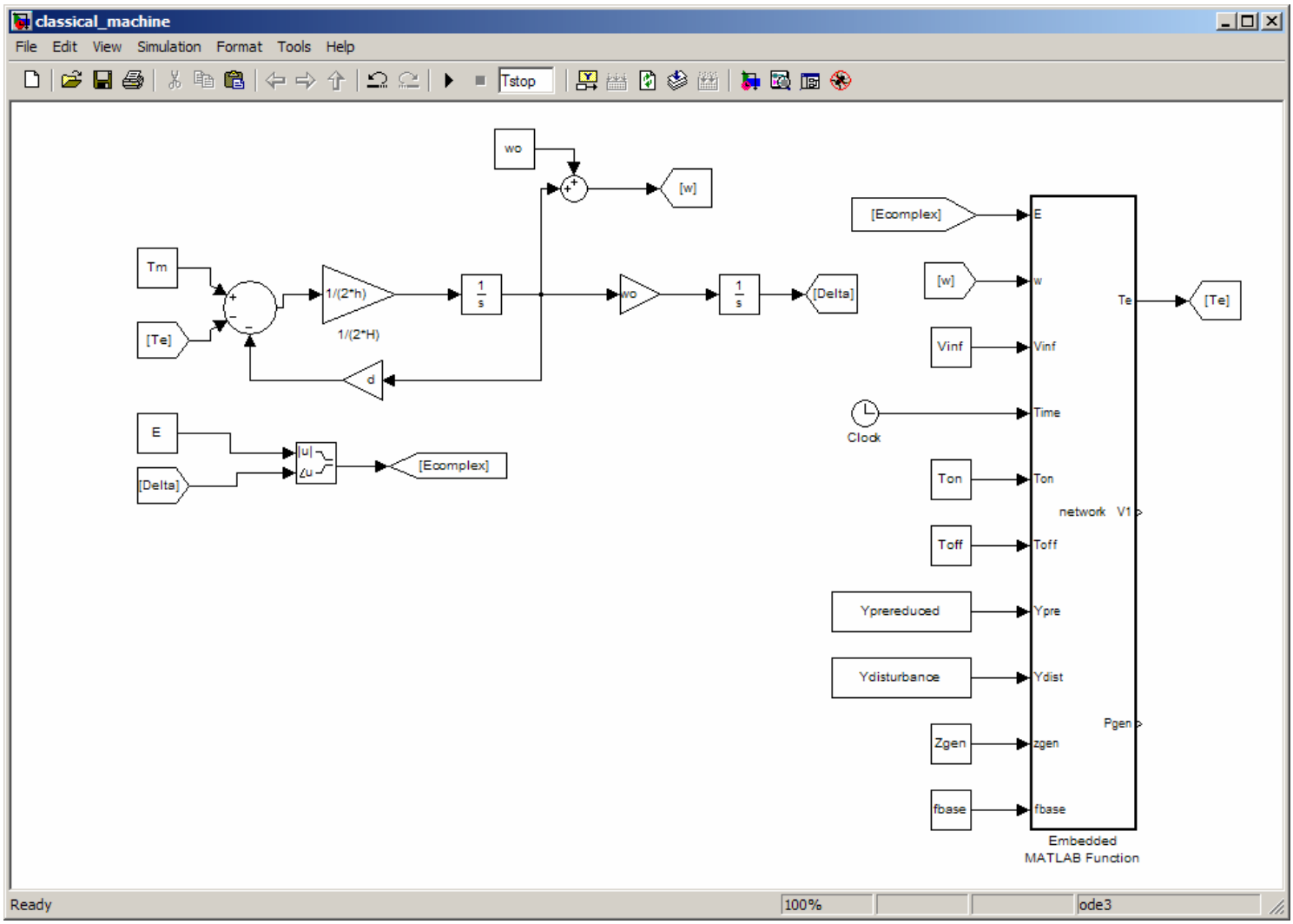


Figure 4.5 Classical Model With Embedded Matlab Function

Use “to workspace” blocks to export simulation results to the Matlab workspace. The variable name property should be set to the name as it should appear in the Matlab workspace and the save format property should be set to Array. The defaults can be used for all other properties. This is shown in Figure 4.6.

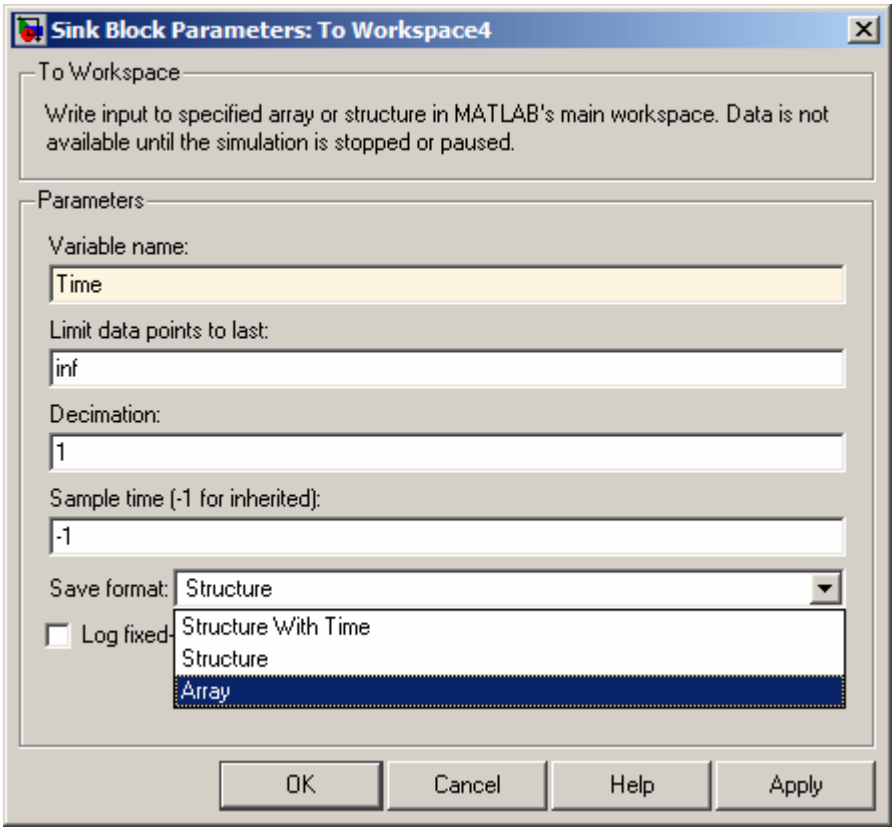


Figure 4.6 To Workspace Settings

In this model we will need to place five variables in the Matlab workspace, the machine angle, delta, the machine speed, speed, the real power generation, pgen, and the terminal voltage, V1, are the variables that will be plotted, it is also very important that the simulation time be exported to the workspace as well. This is shown in Figure 4.7.

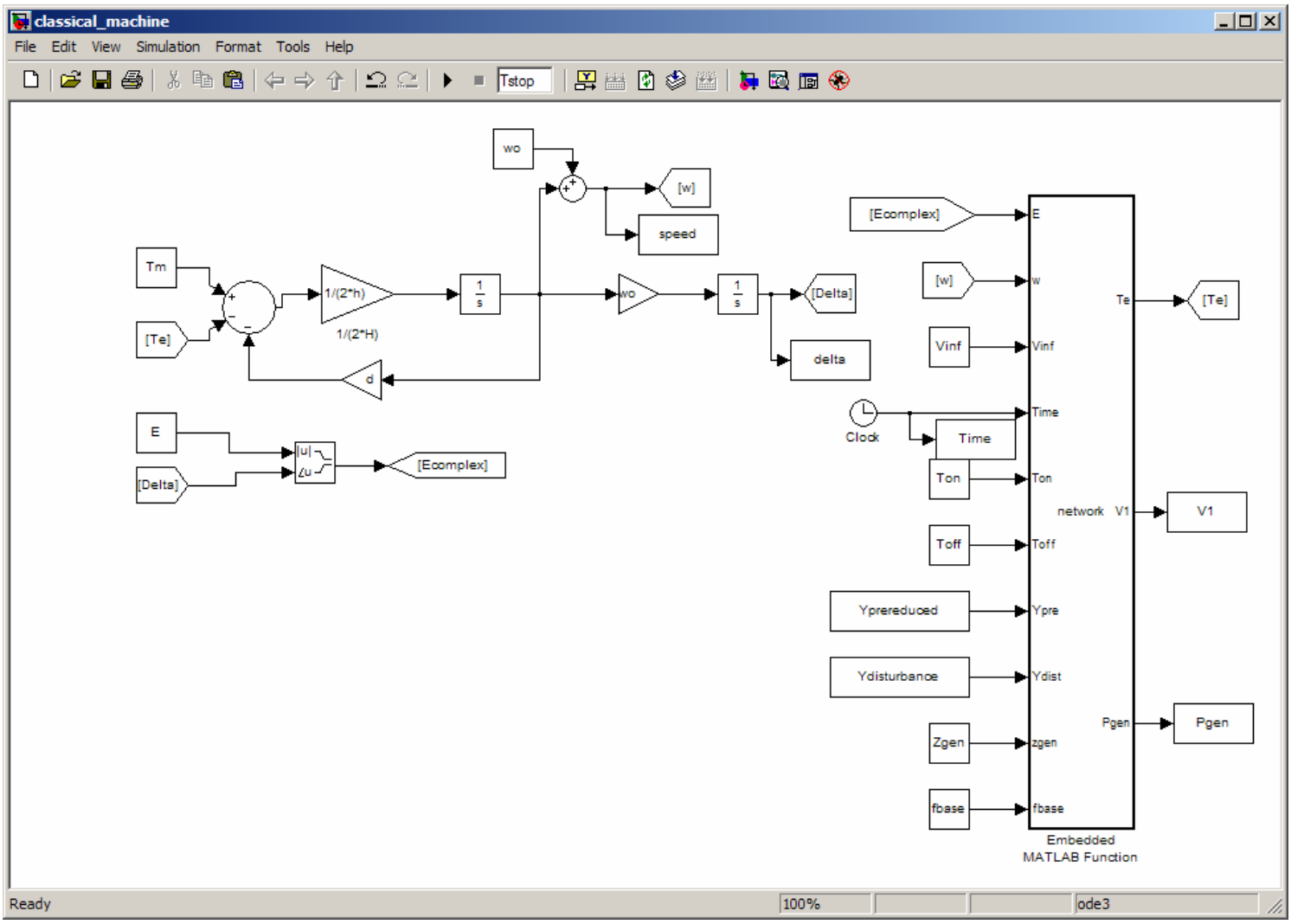


Figure 4.7 Completed Classical Model

The last step in model creation is to modify the configuration parameters. The Configuration Parameters dialog box can be found under the "Simulation" menu. The stop time should be set to Tstop, the solver options should be changed to fixed-step, the ode3 solver is typically used, the fixed-step size should be set to Step_size. This is shown in Figure 4.8.

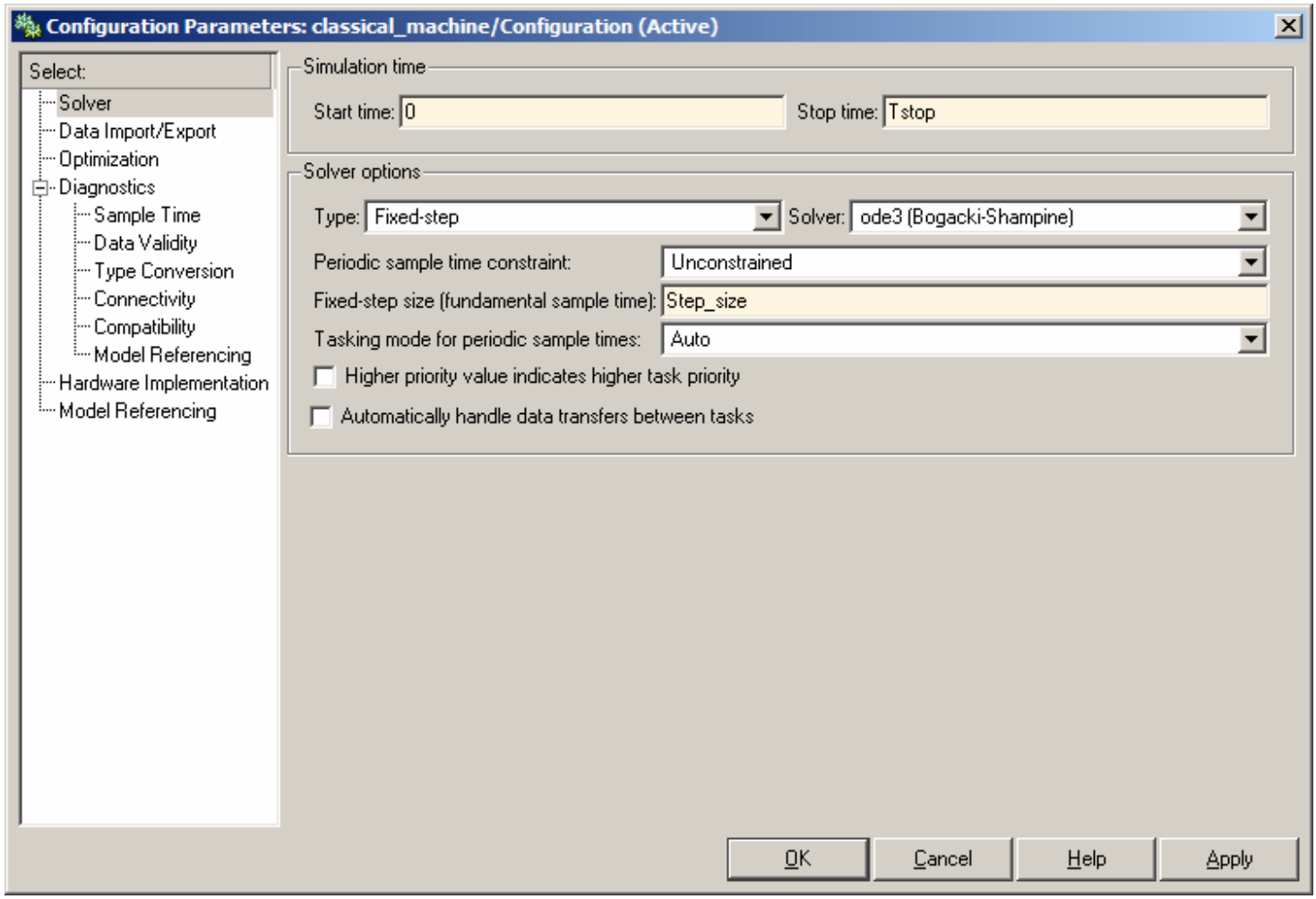


Figure 4.8 Configuration Parameters

4.1.5.3 Creation of Simulation Script

The next step is to create a simulation script that will calculate initial conditions and execute the Simulink model. Standard practice has been to create a simulation script that can be executed without the graphical user interface. This allows the model to be tested apart from the GUI, making the source of any errors more apparent. After testing, the script is edited to make it compatible with the GUI.

The first step in simulation script creation is to create a new Matlab m-file. Standard practice is to give it the name of the model with "sim" added to the end. If the model is named classical_machine, the simulation script would be named classical_machine_sim. The first few lines of code should list of all generator parameters and the corresponding default values. This is shown below. It is very important that all variables spelled and capitalized in exactly the same manner as the Simulink model.

```
h=3;
d=1;
ra=0.05;
```

```
xpd=0.2;
pgen_fault=100;
qgen_fault=30;
v1_fault=1;
t_fault_on=1;
t_fault_off=1.1;
zfault=0;
pgen_reject=100;
qgen_reject=30;
v1_reject=1;
t_reject=2;
mva_base=100;
fbase=60;
rl=0.2;
xl=0.2;
rt=0.1;
xt=0.5;
Tstop=30;
Step_size=0.005;
```

After this a switch statement should be used to determine which test to run. The switched variable should be test_switch. The code for this is below.

```
%Flag to set which test will be executed
%1= Load Rejection
%2= Three Phase Fault
switch test_switch
    case 1
        P1=pgen_fault;
        Q1=qgen_fault;
        V1=v1_fault;
        Ton=t_fault_on;
        Toff=t_fault_off;
    case 2
        P1=pgen_reject;
        Q1=qgen_reject;
        V1=v1_reject;
        Ton=t_reject;
        Toff=100000;
end
```

Next, the initial conditions need to be calculated, these were determined in Section 4.1.5.1. The complete equations can be found below. The data for real and reactive power were supplied in terms of MW and MVAR, they will be perunitized here. The base frequency will also be computed in rad/s.

```
ztran=rt+1j*xt;
zline=rl+1j*xl;
Zgen=ra+1j*xpd;

wo=2*pi*fbase;
P1=P1/mva_base;
Q1=Q1/mva_base;

S = P1+1j*Q1;
I = conj(S/V1);
```

```
E=abs(V1+I*Zgen);
deltao=angle(V1+I*Zgen);
Vinf= V1-(ztran+zline)*I;
Tm=P1;
```

Lines are needed to build the network admittance matrices. These appear below. The switch statement determines which admittance matrix to use during the disturbance. There are many ways to build this particular part of the script. The method used here will be to build full admittance matrices for each condition and then reduce the matrices using the Kron reduction technique.

```
%Build prefault network admittance matrices
%Bus 1- Generator ideal source
%Bus 2- Infinite bus
%Bus 3- Generator Terminals
%Bus 4- High side of the GSU
Ybus=zeros(4,4);
Ybus(1,1)=1/Zgen;
Ybus(1,2)=0;
Ybus(1,3)=-1/Zgen;
Ybus(1,4)=0;

Ybus(2,1)=Ybus(1,2);
Ybus(2,2)=1/zline;
Ybus(2,3)=0;
Ybus(2,4)=-1/zline;

Ybus(3,1)=Ybus(1,3);
Ybus(3,2)=Ybus(2,3);
Ybus(3,3)=1/Zgen+1/ztran;
Ybus(3,4)=-1/ztran;

Ybus(4,1)=Ybus(1,4);
Ybus(4,2)=Ybus(2,4);
Ybus(4,3)=Ybus(3,4);
Ybus(4,4)=1/ztran+1/zline;

%Prepare Admittance matrix for faulted network
Ybusfault=Ybus;
Ybusfault(4,4)=Ybus(4,4)+1/(zfault+.0000001);

%Prepare admittance matrix for load rejected network
Ybusreject=zeros(4,4);
Ybusreject(1,1)=1/Zgen;
Ybusreject(1,2)=0;
Ybusreject(1,3)=-1/Zgen;
Ybusreject(1,4)=0;

Ybusreject(2,1)=Ybus(1,2);
Ybusreject(2,2)=1/zline;
Ybusreject(2,3)=0;
Ybusreject(2,4)=-1/zline;

Ybusreject(3,1)=Ybus(1,3);
```

```
Ybusreject(3,2)=Ybus(2,3);
Ybusreject(3,3)=1/Zgen+1/(99999999);
Ybusreject(3,4)=-1/(99999999);

Ybusreject(4,1)=Ybus(1,4);
Ybusreject(4,2)=Ybus(2,4);
Ybusreject(4,3)=Ybus(3,4);
Ybusreject(4,4)=1/ztran+1/(99999999);


%Use Kron reduction to reduce admittance matrix
Yprereduced=Ybus(1:2,1:2)-
Ybus(1:2,3:4)*inv(Ybus(3:4,3:4))*Ybus(3:4,1:2);
Yreject=Ybusreject(1:2,1:2)-
Ybusreject(1:2,3:4)*inv(Ybusreject(3:4,3:4))*Ybusreject(3:4,1:2);
Yfault=Ybusfault(1:2,1:2)-
Ybusfault(1:2,3:4)*inv(Ybusfault(3:4,3:4))*Ybusfault(3:4,1:2);

switch test_switch
    case 1
        Ydisturbance=Yfault;
    case 2
        Ydisturbance=Yreject;
end
```

Next, a line is needed to run the simulation.

```
sim('classical_machine')
```

For testing purposes, plot commands will be added to the end of the code. These appear below.

```
subplot(4,1,1)
plot(Time,V1)
ylabel('Terminal Voltage')

subplot(4,1,2)
plot(Time,delta)
ylabel('Rotor Angle')

subplot(4,1,3)
plot(Time,w)
ylabel('Speed')

subplot(4,1,4)
plot(Time,pgen)
xlabel('Time (s)')
ylabel('Pgen')
```

The completed simulation script appears below.

```
%Default parameter values
h=3;
d=1;
ra=0.05;
xpd=0.2;
```

```
pgen_fault=100;
qgen_fault=30;
v1_fault=1;
t_fault_on=1;
t_fault_off=1.1;
zfault=0;
pgen_reject=100;
qgen_reject=30;
v1_reject=1;
t_reject=2;
mva_base=100;
fbase=60;
rl=0.2;
xl=0.2;
rt=0.1;
xt=0.5;
Tstop=30;
Step_size=0.005;

%Flag to set which test will be executed
%1= Three Phase Fault
%2= Load Rejection
test_switch=2;
switch test_switch
    case 1
        P1=pgen_fault;
        Q1=qgen_fault;
        V1=v1_fault;
        Ton=t_fault_on;
        Toff=t_fault_off;
    case 2
        P1=pgen_reject;
        Q1=qgen_reject;
        V1=v1_reject;
        Ton=t_reject;
        Toff=100000;
end

ztran=rt+1j*xt;
zline=rl+1j*xl;
Zgen=ra+1j*xpd;

wo=2*pi*fbase;
P1=P1/mva_base;
Q1=Q1/mva_base;

S = P1+1j*Q1;
I = conj(S/V1);
E=abs(V1+I*Zgen);
deltao=angle(V1+I*Zgen);
Vinf= V1-(ztran+zline)*I;
Tm=P1;

%Build prefault network admittance matrices
%Bus 1- Generator ideal source
```

```
%Bus 2- Infinite bus
%Bus 3- Generator Terminals
%Bus 4- High side of the GSU
Ybus=zeros(4,4);
Ybus(1,1)=1/Zgen;
Ybus(1,2)=0;
Ybus(1,3)=-1/Zgen;
Ybus(1,4)=0;

Ybus(2,1)=Ybus(1,2);
Ybus(2,2)=1/zline;
Ybus(2,3)=0;
Ybus(2,4)=-1/zline;

Ybus(3,1)=Ybus(1,3);
Ybus(3,2)=Ybus(2,3);
Ybus(3,3)=1/Zgen+1/ztran;
Ybus(3,4)=-1/ztran;

Ybus(4,1)=Ybus(1,4);
Ybus(4,2)=Ybus(2,4);
Ybus(4,3)=Ybus(3,4);
Ybus(4,4)=1/ztran+1/zline;

%Prepare Admittance matrix for faulted network
Ybusfault=Ybus;
Ybusfault(4,4)=Ybus(4,4)+1/(zfault+.0000001);

%Prepare admittance matrix for load rejected network
Ybusreject=zeros(4,4);
Ybusreject(1,1)=1/Zgen;
Ybusreject(1,2)=0;
Ybusreject(1,3)=-1/Zgen;
Ybusreject(1,4)=0;

Ybusreject(2,1)=Ybus(1,2);
Ybusreject(2,2)=1/zline;
Ybusreject(2,3)=0;
Ybusreject(2,4)=-1/zline;

Ybusreject(3,1)=Ybus(1,3);
Ybusreject(3,2)=Ybus(2,3);
Ybusreject(3,3)=1/Zgen+1/(99999999);
Ybusreject(3,4)=-1/(99999999);

Ybusreject(4,1)=Ybus(1,4);
Ybusreject(4,2)=Ybus(2,4);
Ybusreject(4,3)=Ybus(3,4);
Ybusreject(4,4)=1/ztran+1/(99999999);


%Use Kron reduction to reduce admittance matrix
Yprereduced=Ybus(1:2,1:2)-
   Ybus(1:2,3:4)*inv(Ybus(3:4,3:4))*Ybus(3:4,1:2);
```

```
Yreject=Ybusreject(1:2,1:2)-
   Ybusreject(1:2,3:4)*inv(Ybusreject(3:4,3:4))*Ybusreject(3:4,1:
   2);
Yfault=Ybusfault(1:2,1:2)-
   Ybusfault(1:2,3:4)*inv(Ybusfault(3:4,3:4))*Ybusfault(3:4,1:2);

switch test_switch
    case 1
        Ydisturbance=Yfault;
    case 2
        Ydisturbance=Yreject;
end

sim('classical_machine')

subplot(4,1,1)
plot(Time,V1)
ylabel('Terminal Voltage')

subplot(4,1,2)
plot(Time,rad2deg(delta))
ylabel('Rotor Angle')

subplot(4,1,3)
plot(Time,speed)
ylabel('Speed')

subplot(4,1,4)
plot(Time,Pgen)
xlabel('Time (s)')
ylabel('Pgen')
```

The next step is to run a simulation to check the results. A graph appears in Figure 4.9. These appear to be logical, the next step is to create a GUI setting file. The Simulink model and simulation script should be copied into the directory containing the main graphical user interface and library files.

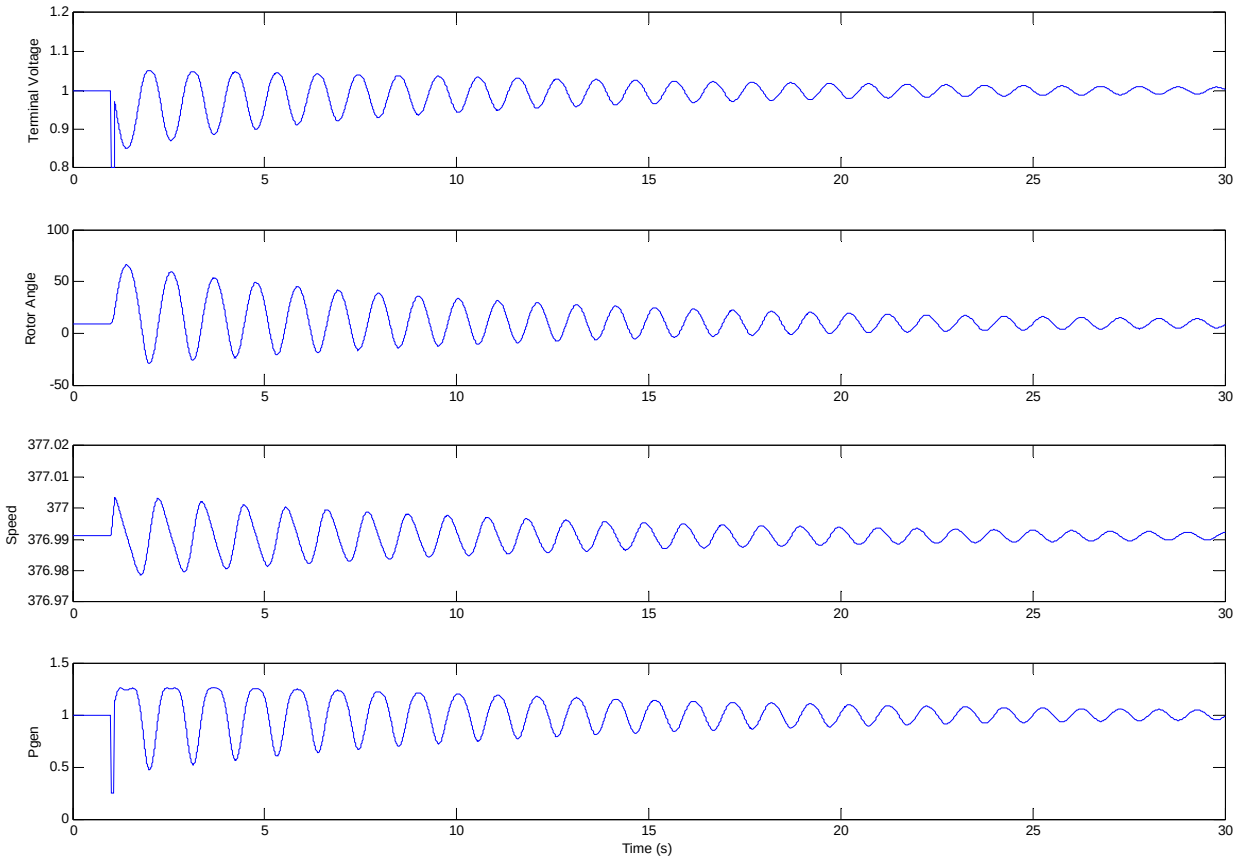


Figure 4.9 Simulation Results

4.1.5.4 Creation of GUI Setting File

The GUI setting file is a Matlab script that sets up the data structures needed by the GUI to properly initialize. The fields needed are described in Table 3.2. If the model to be added utilizes either the Genrou or Gensal models, the setting file for these models can be copied and modified as needed. This can save a great deal of time. In this case, the model to be added is not similar to an existing setting file, a new one will be created from scratch.

The first step is to create a new m-file. This should be saved in the same folder as the main graphical user interface and library files as "classical_machine_setting_file.m." The first few lines of code should clear and set up a structure called parameter_setting. These lines appear below:

```
clear parameter_setting;
parameter_setting=struct(...
```

This structure will have 11 fields, workspace_name, min_value, max_value, default_value, previous_value, current_value, display_name, description, color,

slider_panel, and editability. The next step is to create the workspace_name field. This field should contain the name of each variable as it is used in the simulation script and block diagram. The order that these appear in is of great strategic importance as it is the order in which they will appear on the main GUI and should be maintained for future fields. The standard practice has been to group the parameters into several broad groups including generator parameters, initial conditions (terminal voltage and real and reactive power injections for each test), test or disturbance parameters (fault impedance, disturbance time, etc), network parameters (network impedances and base power and frequency), simulation parameters, and parameters corresponding to any applicable subsystems such as an exciter or a turbine/governor model. The code for the workspace_name field appears below.

```
'workspace_name',{...
    'h','d','ra','xpd',...
    'pgen_fault','qgen_fault','v1_fault',...
    'pgen_reject','qgen_reject','v1_reject',...
    't_fault_on','t_fault_off','zfault',...
    't_reject',...
    'rt','xt','rl','xl','mva_base','fbase',...
    'Tstop', 'Step_size' ...
    },...
```

The next step is to create the min_value field. This field contains the minimum values for each slider bar on the main GUI. It is very important that the entries in this field be in the same order as the workspace_name field. The minimum values were previously determined and appear in Table 4.1. The code appears below.

```
'min_value',{...
    1, 0, 0, .1,...
    0, -500, 0,...
    0, -500, 0,...
    0, 0, 0,...
    0,...
    0, 0.001, 0, 0.001, 1, 50,...
    1, .0001 ...
    },...
```

The next field is the max_value field. This field contains the maximum value of each slider bar. These values were previously determined and appear in Table 4.1. The code appears below.

```
'max_value',{...
    7,2,.05,.5,...
    500, 500, 1.05,...
    500, 500, 1.05,...
    10, 10, 10,...
    10,...
    .5, 1, .5, 1, 500, 60,...
    60, .01,...
    },...
```

The next field contains the information needed to set the default values for each edit box.

```
'default_value',{...
```

```
    3,1,.05,.2,...
    100, 30, 1,...
    100, 30, 1, ...
    1,1.1,0, ...
    1,...
    .1,.5,.2,.2,100,60,...
    30, .005 ...
    },...
```

The previous_value field contains information for the undo/redo commands. In the setting file it is set to 0. The code for this appears below.

```
'previous_value',{0},...
```

In the setting file, current_value field is the same as the default_value field. These may be changed in The code for this appears below.

```
'current_value',{...
    3,1,.05,.2,...
    100, 30, 1,...
    100, 30, 1, ...
    1,1.1,0, ...
    1,...
    .1,.5,.2,.2,100,60,...
    30, .005 ...
    },...
```

The next field, display_name is the name of each parameter as it will appear on the GUI. These do not need to be the same as the workspace name or the variables in the Simulink model or Simulation script, but a knowledgeable user should be able to understand what it is without trouble. Be sure that the name is not more than 7 or 8 characters long as this can make the parameter titles appear to run together. The code for the display names appears below.

```
'display_name',{...
    'H','D','Ra','Xpd',...
    'P_fault','Q_fault','V1_fault',...
    'P_rjct','Q_rjct','V1_rjct',...
    't_flt_on','t_flt_off','Zfault',...
    't_reject',...
    'Rt','Xt','Rl','Xl','S_base','fbase',...
    'Tstop', 'Step_size' ...
    },...
```

The description field is not currently used, but is still included as an empty field.

```
'description',{''},...
```

The color field determines the color of the edit box. This feature is intended to help the user visually group certain parameters and find the parameter that he wishes to adjust more quickly. This field can be any of the standard Matlab colors such as ‘yellow’ or ‘white’, or can be a 1 row, 3 column matrix that sets the colors that the colors manually. The colors should be fairly light and transparent to allow the text in the edit box to be readable. If the parameters are laid out well and pleasing colors are chosen, this can be a very useful feature. The standard practice has been to use yellow for generator parameters, white for initial conditions, red for network parameters,

purple for simulation settings, green for exciter parameters and blue for turbine/governor parameters. The code for this field appears below.

```
'color',{...
  'yellow','yellow','yellow','yellow',...
  'white','white','white',...
  'white','white','white',...
  'white','white','white'...
  'white',...
  [1 .4 .4],[1 .4 .4],[1 .4 .4],[1 .4 .4],[1 .4 .4],[1 .4 .4],...
  [.7 .7 .9],[.7 .7 .9] ...
  },...
```

The slider_panel field was once used to group the parameters into sub-panels though this field is no longer used, standard practice has been to continue including it. The code for this appears below.

```
'slider_panel',{...
    1,1,1,1,...
    2,2,2,...
    2,2,2,...
    2,2,2,...
    2,...
    3,3,3,3,3,3,...
    4,4 ...
    },...
```

The last field in the parameter_setting structure is the editability field. This field is made up of integers. A 0 means that that particular parameter is editable regardless of the position of the test menu. If the value is set to 1 it will be editable only when the test menu is set to position 1, if the value is set to 2, it will only be editable when the test menu is set to 3, etc. The code for this appears below.

```
    'editability',{...
        0,0,0,0,...
        1,1,1,...
        2,2,2,...
        1,1,1,...
        2,...
        0,0,0,0,0,0,...
        0,0 ...
        }...
);
```

Next, the script should be executed to make sure that there is not a problem. The most common errors in setting files result from one of the field having more entries than the others. If this error occurs, count the number of entries in each field.

The output_setting field is normally the same for all models, unfortunately, the standard outputs are not logical for this model. The output_setting structure contains the information needed for the plots. The workspace_name field contains the names of the arrays that will be plotted as they appear in the Simulink model. The code for this appears below.

```
output_setting=struct(...
    'workspace_name',{...
```

```
            'V1','Pgen','delta','speed'...
        },...
```

The start_time and end_time fields are not used in current versions, but are still included by standard practice. The code appears below.

```
'start_time', {0},...
'end_time', {10},...
```

The display_name is the label that gets displayed on the Y axis. Common practice is to indicate the units in brackets after the name. This code appears below.

```
'display_name', {...
    'V1 [pu]','Pgen [pu]','Delta [rad]','speed [rad/s]'...
},...
```

The test_data, simulation_data, old_simulation_data, and test_time fields are used to store simulation and test data. They are initially set to empty fields, but the home screen will store arrays in them at a later time. It is important that the test_data, simulation_data, and old_simulation_data fields be set to 'x'. The GUI uses these values to choose what to plot. The code for this appears below.

```
    'test_data',{'x'},...
    'simulation_data',{'x'},...
    'old_simulation_data',{'x'},...
    'test_time',{0}...
);
```

The tests_setting structure is usually the same for all models. Because it does not make sense to simulate a voltage step for this model, there will only be two tests. It is important that the test listed first be the same test that corresponds to an editablity of 1 in the parameter_setting.editability field. The code appears below.

```
tests_setting=struct(...
    'test_name',{...
        'Three Phase Fault','Load Rejection'...
        }...
);
```

The last three lines store information about where the model files are located and what the title on the home window should be. simulin_file_name is a string that contains the name of the Simulink model. simulation_file stores the title of the GUI. This can be any name that you wish. simulation_script stores the name of the simulation script. Extensions should not be used on either simulin_file_name or simulation_script.

```
simulin_file_name='classical_machine';
simulation_file='Classical Model';
simulation_script='classical_machine_sim';
```

At this point the setting file should be executed to ensure that there are not any errors. The complete GUI setting file appears below.

```
clear parameter_setting;
parameter_setting=struct(...
    'workspace_name',{...
        'h','d','ra','xpd',...
        'pgen_fault','qgen_fault','v1_fault',...
```

```
        'pgen_reject','qgen_reject','v1_reject',...
        't_fault_on','t_fault_off','zfault',...
        't_reject',...
        'rt','xt','rl','xl','mva_base','fbase',...
        'Tstop', 'Step_size' ...
        },...
    'min_value',{...
        1, 0, 0, .1,...
        0, -500, 0,...
        0, -500, 0,...
        0, 0, 0,...
        0,...
        0, 0.001, 0, 0.001, 1, 50,...
        1, .0001 ...
        },...
    'max_value',{...
        7,2,.05,.5,...
        500, 500, 1.05,...
        500, 500, 1.05,...
        10, 10, 10,...
        10,...
        .5, 1, .5, 1, 500, 60,...
        60, .01 ...
        },...
    'default_value',{...
        3,1,.05,.2,...
        100, 30, 1,...
        100, 30, 1, ...
        1,1.1,0, ...
        1,...
        .1,.5,.2,.2,100,60,...
        30, .005 ...
        },...
    'previous_value',{0},...
    'current_value',{...
        3,1,.05,.2,...
        100, 30, 1,...
        100, 30, 1, ...
        1,1.1,0, ...
        1,...
        .1,.5,.2,.2,100,60,...
        30, .005 ...
        },...
    'display_name',{...
        'H','D','Ra','Xpd',...
        'P_fault','Q_fault','V1_fault',...
        'P_rjct','Q_rjct','V1_rjct',...
        't_flt_on','t_flt_off','Zfault',...
        't_reject',...
        'Rt','Xt','Rl','Xl','S_base','fbase',...
        'Tstop', 'Step_size' ...
        },...
    'description',{''},...
    'color',{...
        'yellow','yellow','yellow','yellow',...
        'white','white','white',...
```

```
            'white','white','white',...
            'white','white','white'...
            'white',...
            [1 .4 .4],[1 .4 .4],[1 .4 .4],[1 .4 .4],[1 .4 .4],[1 .4
.4],...
            [.7 .7 .9],[.7 .7 .9] ...
            },...
       'slider_panel',{...
            1,1,1,1,...
            2,2,2,...
            2,2,2,...
            2,2,2,...
            2,...
            3,3,3,3,3,3,...
            4,4 ...
            },...
        'editability',{...
            0,0,0,0,...
            1,1,1,...
            2,2,2,...
            1,1,1,...
            2,...
            0,0,0,0,0,0,...
            0,0 ...
            }...
    );

    output_setting=struct(...
        'workspace_name',{...
            'V1','Pgen','delta','speed'...
        },...
        'start_time', {0},...
        'end_time', {10},...
        'display_name', {...
            'V1 [pu]','Pgen [pu]','Delta [rad]','speed [rad/s]'...
        },...
        'test_data',{'x'},...
        'simulation_data',{'x'},...
        'old_simulation_data',{'x'},...
        'test_time',{0}...
    );

    tests_setting=struct(...
        'test_name',{...
            'Three Phase Fault','Load Rejection'...
            }...
    );
    simulin_file_name='classical_machine';
    simulation_file='Classical Model';
    simulation_script='classical_machine_sim';
```

4.1.5.5 Modification of Main Window Setting File

The main window setting file contains the information needed to display the list in the opening screen and execute the correct GUI setting file. This does not need to be

created again from scratch, it simply needs to modified so that the new model will be displayed in the list box. The code for the new main window setting file appears below.

```
model_setting=struct(...
    'model_name',{...
    'Genrou',...
    'Genrou exst4b',...
    'Genrou rexs',...
    'Gensal',...
    'Gensal exst1',...
    'Gensal exst1 Hygov',...
    'Classical Model'
    },...
    'model_folder',{...
    ''...
    ''...
    ''...
    ''...
    ''...
    ''...
    ''
    },...
    'setting_file_name',{...
    'genrou_setting_file',...
    'genrou_exst4b_setting_file',...
    'genrou_rexs_setting_file',...
    'gensal_setting_file',...
    'gensal_exst1_setting_file',...
    'gensal_exst1_hygov_setting_file',...
    'classical_machine_setting_file'
    }...
);
```

The modifications made were to add a string “Classical Model’ to the model_name field, an extra set of quotation marks to the model_folder field and “classical_machine_setting_file” to the the setting_file_name field. The model_name field stores the name of the model as it appears in the list on the opening window. The model_folder field is not used by current versions, simply place ‘’ in this field. The setting_file_name field should be the name of the setting file for that model with out the extension.

4.1.5.6 Final Simulation Script Modifications

The final step to adding the model to the library to is to comment out the lines of code in the beginning of the simulation script that set the default values for each parameter and that graph the data. The final simulation script appears below.

```
% %Default parameter values
% h=3;
% d=1;
% ra=0.05;
% xpd=0.2;
% pgen_fault=100;
```

```
% qgen_fault=30;
% v1_fault=1;
% t_fault_on=1;
% t_fault_off=1.1;
% zfault=0;
% pgen_reject=100;
% qgen_reject=30;
% v1_reject=1;
% t_reject=2;
% mva_base=100;
% fbase=60;
% rl=0.2;
% xl=0.2;
% rt=0.1;
% xt=0.5;
% Tstop=30;
% Step_size=0.005;

%Flag to set which test will be executed
%1= Three Phase Fault
%2= Load Rejection
%test_switch=2;
switch test_switch
    case 1
        P1=pgen_fault;
        Q1=qgen_fault;
        V1=v1_fault;
        Ton=t_fault_on;
        Toff=t_fault_off;
    case 2
        P1=pgen_reject;
        Q1=qgen_reject;
        V1=v1_reject;
        Ton=t_reject;
        Toff=100000;
end

ztran=rt+1j*xt;
zline=rl+1j*xl;
Zgen=ra+1j*xpd;

wo=2*pi*fbase;
P1=P1/mva_base;
Q1=Q1/mva_base;

S = P1+1j*Q1;
I = conj(S/V1);
E=abs(V1+I*Zgen);
deltao=angle(V1+I*Zgen);
Vinf= V1-(ztran+zline)*I;
Tm=P1;

%Build prefault network admittance matrices
%Bus 1- Generator ideal source
%Bus 2- Infinite bus
```

```
%Bus 3- Generator Terminals
%Bus 4- High side of the GSU
Ybus=zeros(4,4);
Ybus(1,1)=1/Zgen;
Ybus(1,2)=0;
Ybus(1,3)=-1/Zgen;
Ybus(1,4)=0;

Ybus(2,1)=Ybus(1,2);
Ybus(2,2)=1/zline;
Ybus(2,3)=0;
Ybus(2,4)=-1/zline;

Ybus(3,1)=Ybus(1,3);
Ybus(3,2)=Ybus(2,3);
Ybus(3,3)=1/Zgen+1/ztran;
Ybus(3,4)=-1/ztran;

Ybus(4,1)=Ybus(1,4);
Ybus(4,2)=Ybus(2,4);
Ybus(4,3)=Ybus(3,4);
Ybus(4,4)=1/ztran+1/zline;

%Prepare Admittance matrix for faulted network
Ybusfault=Ybus;
Ybusfault(4,4)=Ybus(4,4)+1/(zfault+.0000001);

%Prepare admittance matrix for load rejected network
Ybusreject=zeros(4,4);
Ybusreject(1,1)=1/Zgen;
Ybusreject(1,2)=0;
Ybusreject(1,3)=-1/Zgen;
Ybusreject(1,4)=0;

Ybusreject(2,1)=Ybus(1,2);
Ybusreject(2,2)=1/zline;
Ybusreject(2,3)=0;
Ybusreject(2,4)=-1/zline;

Ybusreject(3,1)=Ybus(1,3);
Ybusreject(3,2)=Ybus(2,3);
Ybusreject(3,3)=1/Zgen+1/(99999999);
Ybusreject(3,4)=-1/(99999999);

Ybusreject(4,1)=Ybus(1,4);
Ybusreject(4,2)=Ybus(2,4);
Ybusreject(4,3)=Ybus(3,4);
Ybusreject(4,4)=1/ztran+1/(99999999);


%Use Kron reduction to reduce admittance matrix
Yprereduced=Ybus(1:2,1:2)-
Ybus(1:2,3:4)*inv(Ybus(3:4,3:4))*Ybus(3:4,1:2);
```

```
Yreject=Ybusreject(1:2,1:2)-
Ybusreject(1:2,3:4)*inv(Ybusreject(3:4,3:4))*Ybusreject(3:4,1:2);
Yfault=Ybusfault(1:2,1:2)-
Ybusfault(1:2,3:4)*inv(Ybusfault(3:4,3:4))*Ybusfault(3:4,1:2);

switch test_switch
    case 1
        Ydisturbance=Yfault;
    case 2
        Ydisturbance=Yreject;
end

sim('classical_machine')

% subplot(4,1,1)
% plot(Time,V1)
% ylabel('Terminal Voltage')
%
% subplot(4,1,2)
% plot(Time,rad2deg(delta))
% ylabel('Rotor Angle')
%
% subplot(4,1,3)
% plot(Time,speed)
% ylabel('Speed')
%
% subplot(4,1,4)
% plot(Time,Pgen)
% xlabel('Time (s)')
% ylabel('Pgen')
```

4.2 Testing Library Additions

It is very important that the model be tested after addition to ensure that the setting file and simulation script were properly built. If the model's accuracy has already been tested against known control data such as simulation results from a PSLF study, then the user can simulate each test and make sure that the results are logical. Additionally, the each parameter should be tested to make sure that adjusting it has an effect on the simulation results.

4.3 Troubleshooting Library Additions

There are several mistakes that can be made while adding models to the library. This section attempts to describe some of the more common errors. These errors will be divided based on the area where the mistake was made. The two most common places for errors are the GUI setting file and the simulation script. This list of errors is by no means exhaustive and was prepared assuming that the original block diagram and simulation script were working properly and giving accurate results before addition to the library.

4.3.1 Errors in Main Window Setting File

The following errors can be attributed to the main window setting file. Errors in this are rare, though they do occur.

- Error in main_window at line 32.
    - This can mean that one of the fields in the model_setting structure is not the same length as the others. It can also indicate a problem with the GUI setting file. The best way to troubleshoot this error is to try executing each script separately to isolate the error. Count the number of entries in each field of the problematic file.
- Error in main_window at line 248.
    - This can mean that the name of the setting file in the model_setting structure is incorrect. Check to be sure that the name of the setting file is correct.

4.3.2 Errors in GUI Setting File

Errors in the GUI setting file are quite common and are mostly related to typographical errors. Common ones appear below.

- Error in main_window at 32
    - This can mean that one of the fields in the parameter_setting or output_setting structure is not the same length as the others. It can also indicate a problem with the main window setting file. The best way to troubleshoot this error is to try executing each script separately to isolate the error. Count the number of entries in each field of the problematic file.
- Simulation Error.
    - This can indicate a lot of problems including numerical errors with in the model. One possible error in the GUI setting file that could cause this is that the name of the simulation script in the simulation_script string. Check to be sure that this is correct and does not include the extension.
    - Another possible problem is that one of the variable names in the parameter_setting.workspace_name field is incorrect. Check to be sure that all of the variables in this field are the same as they appear in the simulation script and Simulink model.
- Error in GUI at 222.
    - Check to be sure that the variable names in the output_setting structure are spelled correctly and that a corresponding “to workspace” block appears in the Simulink model. Also be sure that the “to workspace” block’s save format is set to array.

4.3.3 Errors in Simulation Script

There are a few places where errors could occur in the simulation script. The most important ones appear below.

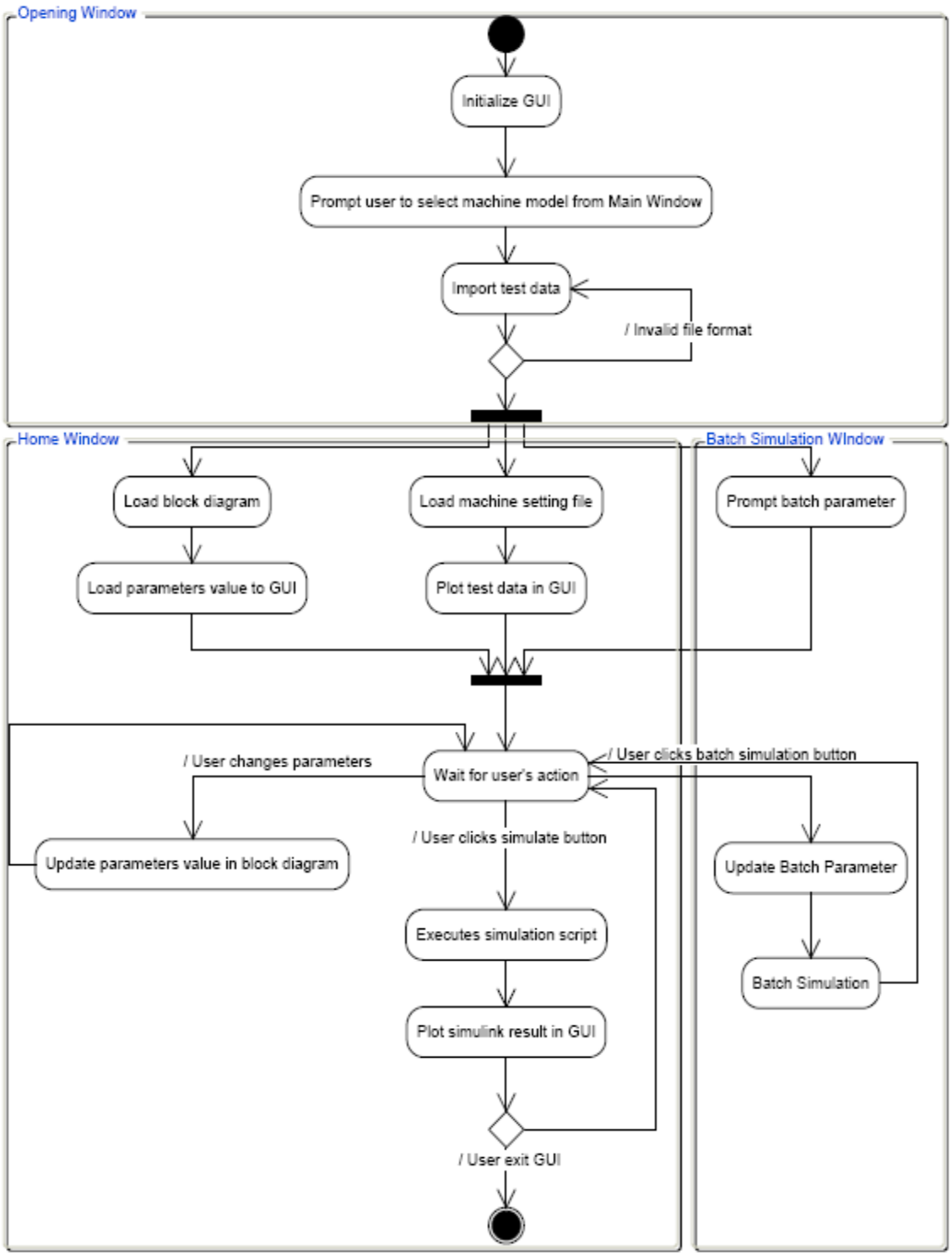
- Model simulates a different test than what is selected in the test menu.
    - Check the opening switch statement and the tests_setting data structure to ensure that the order is the same and that the first entry in the tests_setting structure is the same test as the first case in the switch statement.
    - Check the end of the simulation script to ensure that the correct admittance matrix is assigned.
- Simulation results are incorrect.
    - Check that the proper Simulink model is executed at the end of the simulation script.
    - Check the calculations in the simulation script to ensure that they are accurate.

4.3.4 Errors in Simulink Block Diagram

There is much room for error in the Simulink block diagram and incorrect or inaccurate simulations results frequently result from this. Assuming that the block diagram was working properly before being added to the library, there are really only a few possible errors.

- Error in GUI at 222.
    - Check to be sure that there is a to workspace block for every output and that the variable name field is spelled the same as it is in the output_setting data structure.
- Simulation Error dialog box appears.
    - This could be a numerical error related to the combination of parameters that resulted in a divide by 0. This occurs, though rarely. Try changing a one or more of the parameters and resimulate.
    - This could indicate that one of the variable names is not correct. Check all of the constant blocks and any other places where variables were used to be sure that the output_setting.workspace name fields and usage in the Simulink block diagram are identical.
- Simulation time and/or step size are not adjustable via the GUI.
    - Go to the Simulation menu and choose “Configuration Parameters.” Check to be sure that the stop time is set to Tstop and that the step size is set to Step_size.

Appendix A Detailed Flow Chart


Opening Window
Initialize GUI
Prompt user to select machine model from Main Window
Import test data
/ Invalid file format
Home Window
Batch Simulation WIndow
Load block diagram
Load machine setting file
Prompt batch parameter
Load parameters value to GUI
Plot test data in GUI
/ User changes parameters
Wait for user's action
/ User clicks batch simulation button
/ User clicks simulate button
Update parameters value in block diagram
Update Batch Parameter
Executes simulation script
Batch Simulation
Plot simulink result in GUI
/ User exit GUI

Appendix B Sample Test Data

Time, sec	Vt, pu	Efd, pu	Spd, pu	Ifd, pu
0.01	0.838	0.080	1.911961	0
0.02	1.024	1.053	1.912173	0
0.03	1.024	1.343	0.999919	0
0.04	1.024	1.354	1.000052	0
0.05	1.024	1.362	0.999749	0
0.06	1.025	1.370	0.999986	0
0.07	1.023	1.340	1.000011	0
0.08	1.024	1.311	1.000044	0
0.09	1.024	1.336	0.999877	0
0.10	1.024	1.341	0.999898	0
0.11	1.024	1.337	1.000077	0
0.12	1.024	1.321	0.999906	0
0.13	1.024	1.327	0.999855	0
0.14	1.024	1.352	0.999912	0
0.15	1.024	1.351	0.999923	0
0.16	1.024	1.308	0.999853	0
0.17	1.024	1.320	0.999923	0
0.18	1.024	1.324	0.999948	0
0.19	1.024	1.334	0.999877	0
0.20	1.024	1.330	0.999842	0
0.21	1.024	1.315	1.000073	0
0.22	1.024	1.332	1.000003	0
0.23	1.024	1.329	0.999991	0
0.24	1.024	1.358	0.999722	0

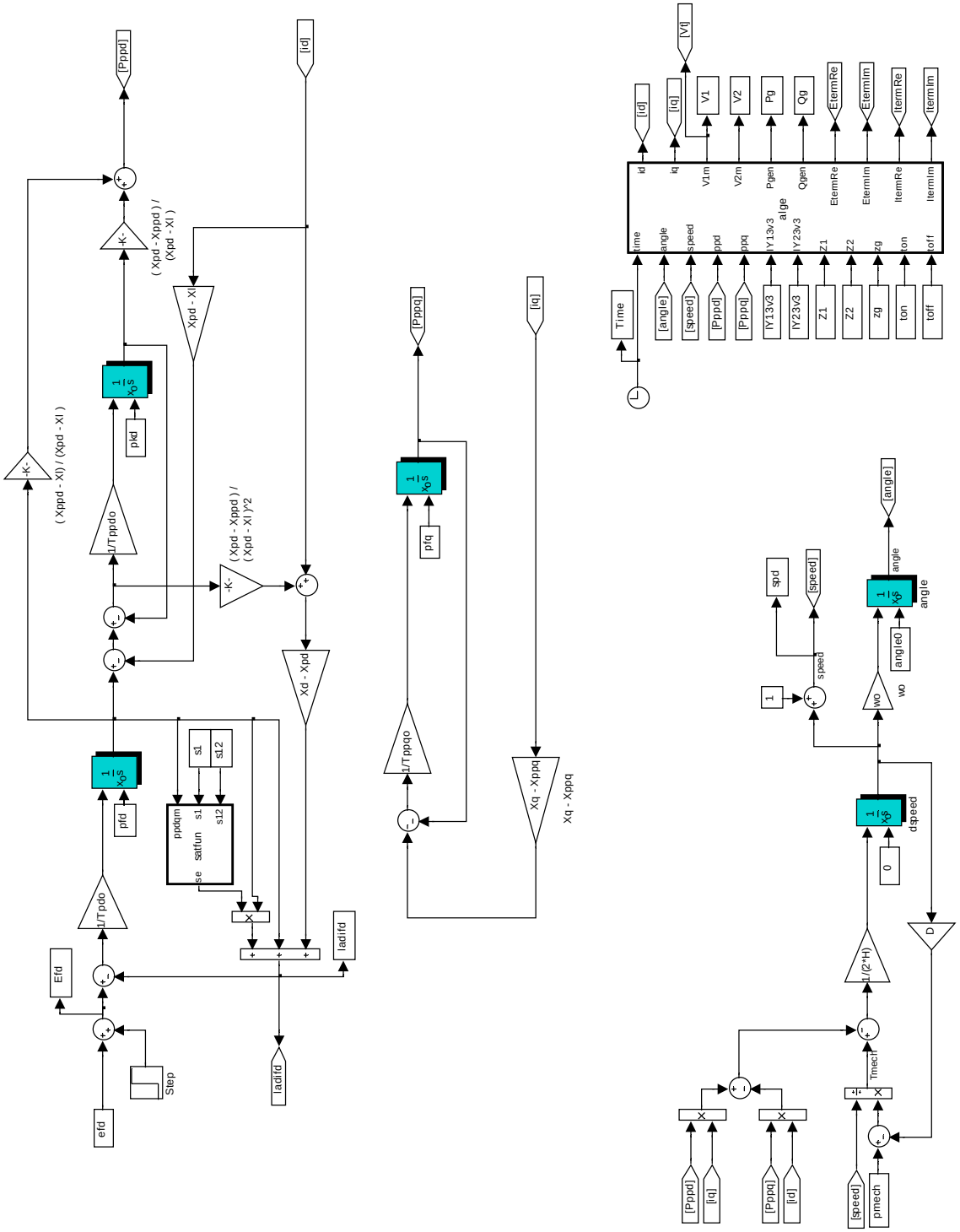
Appendix C Sample GUI Setting File

```
clear parameter_setting;
parameter_setting=struct(...
    'workspace_name',{...
        'tpdo','tppdo','tppqo','h','d','ld','lq',...
        'lpd','lppd','ll','s1','s12','ra','rcomp','xcomp',...
        'Pgen_Vstep','Qgen_Vstep','V1_Vstep',...
        'Pgen_Ld_Reject','Qgen_Ld_Reject','V1_Ld_Reject',...
        'Pgen_Flt','Qgen_Flt','V1_Flt',...
        'Tup_Vstep','Vup_Vstep',...
        'Treject_Ld_Reject',...
        'T_flt_on','T_flt_off','Zfault',...
        'Rt','Xt','Rl','Xl','MVA_machine','MVA_system','fbase',...
        'Tstop', 'Step_size' ...
        },...
    'min_value',{...
        2, .01, .01, .5, 0, .5, .5,...
        .1, .1, .1, .01, .1, 0, 0, -.1,...
        0, -1000, 0,...
        0, -1000, 0,...
        0, -1000, 0,...
        0, -100,...
        0,...
        0,0,0,...
        0, 0, 0, 0, 1, 1, 0,...
        0, .001 ...
        },...
    'max_value',{...
        15, .1, .1, 5, 5, 2.5, 2.5,...
        .3, .3, .3, .5, 1, .01, .1, .1,...
        1000, 1000, 1.05,...
        1000, 1000, 1.05,...
        1000, 1000, 1.05,...
        10, 100 ,...
        10,...
        10,10,100,...
        10, 10, 10, 10, 1000, 1000, 100,...
        60, .01 ...
        },...
    'default_value',{...
        7, .03, .035, 3, 0, 1.2, .8,...
        .22, .2, .16, .05, .3, 0, 0, 0,...
        100, 32.09, 1.05, ...
        100, 32.09, 1.05, ...
        100, 32.09, 1.05, ...
        1,1,...
        1,...
        1,1.1,0,...
        0, .1, 0, .2, 120, 100, 60,...
        30, .004 ...
        },...
    'previous_value',{0},...
    'current_value',{...
        7, .03, .035, 3, 0, 1.2, .8,...
        .22, .2, .16, .05, .3, 0, 0, 0,...
```

```
        100, 32.09, 1.05, ...
        100, 32.09, 1.05, ...
        100, 32.09, 1.05, ...
        1,1,...
        1,...
        1,1.1,0,...
        0, .1, 0, .2, 120, 100, 60,...
        30, .004 ...
        },...
    'display_name',{...
        'Tpdo','Tppdo','Tppqo','H','D','Ld','Lq',...
        'Lpd','Lppd','Ll','S1','S12','Ra','Rcomp','Xcomp',...
        'Pgen_Vstp','Qgen_Vstp','V1_Vstp',...
        'Pgen_Rjct','Qgen_Rjct','V1_Rjct',...
        'Pgen_Flt','Qgen_Flt','V1_Flt',...
        'Tup_Vstep','%V_Vstep',...
        'T_Rjct',...
        'T_flt_on','T_flt_off','Zfault',...
        'Rt','Xt','Rl','Xl','MVA_mach','MVA_sys','fbase',...
        'Tstop', 'Step_Size' ...
        },...
    'description',{''},...
    'color',{...

'yellow','yellow','yellow','yellow','yellow','yellow','yellow',...

'yellow','yellow','yellow','yellow','yellow','yellow','yellow','yellow'
,...
        'white','white','white',...
        'white','white','white',...
        'white','white','white',...
        'white','white',...
        'white',...
        'white','white','white',...
        [1 .4 .4],[1 .4 .4],[1 .4 .4],[1 .4 .4],[1 .4 .4],[1 .4 .4],[1
.4 .4],...
        [.7 .7 .9],[.7 .7 .9] ...
        },...
   'slider_panel',{...
        1,1,1,1,1,1,1,...
        1,1,1,1,1,1,1,1,...
        2,2,2,...
        2,2,2,...
        2,2,2,...
        2,2,...
        2,...
        2,2,2,...
        3,3,3,3,3,3,3,...
        4,4 ...
        },...
    'editability',{...
        0,0,0,0,0,0,0,...                    %0 - All Tests
        0,0,0,0,0,0,0,0,...                  %1 - Test 1 Only
        1,1,1,...                              %2 - Test 2 Only
        2,2,2,...                              %3 - Test 3 Only
        3,3,3,...                              %4 - Test 4 Only
```

```
        1,1,...                                     % etc
        2,...
        3,3,3,...
        0,0,0,0,0,0,0,...
        0,0 ...
        }...
);

output_setting=struct(...
    'workspace_name',{...
        'V1','Efd','spd','ladifd'...
    },...
    'start_time', {0},...
    'end_time', {10},...
    'display_name', {...
        'V1_t [pu]','Efd [pu]','speed [pu]','ladifd [pu]'...
    },...
    'test_data',{'x'},...
    'simulation_data',{'x'},...
    'old_simulation_data',{'x'},...
    'test_time',{0}...
);

tests_setting=struct(...
    'test_name',{...
        'Voltage Step','Load Rejection','Three Phase Fault'...
        }...
);
simulin_file_name='SMIBgensal_v1';
simulation_file='Gensal Model';
simulation_script='SMIBgensal_sim';
```

Appendix D Sample Simulink Block Diagram



SMIB
02/15/07

Appendix E Sample Simulation Script

```
% 021507

% Set default times (fault on, fault off and V ref step
   ton  = 9999.;
   toff = 9999.;
   VrefTime = 9999.;
   VrefStep = 0.00;

% % Event flags.  Set to one to simulate desired event
%    apply_fault     = 0;
%    trip_gsu        = 1;
%
% % Event times
%    if apply_fault
%         ton  = 1.0;
%         toff = 1.1;
%    end
%    if trip_gsu
%         ton  = 1.0;
%         toff = 9999.;
%    end

   switch test_switch
       case 1
        apply_fault     = 0;
        trip_gsu        = 0;
        apply_vref_step = 1;
        pgen = Pgen_Vstep;
        qgen = Qgen_Vstep;
        vm = V1_Vstep;
%        va = Theta1_Vstep*pi/180;
        VrefStep = .01*Vup_Vstep;
        VrefTime = Tup_Vstep;
       case 2
        apply_fault     = 0;
        trip_gsu        = 1;
        apply_vref_step = 0;
        pgen = Pgen_Ld_Reject;
        qgen = Qgen_Ld_Reject;
        vm = V1_Ld_Reject;
%        va = Theta1_Ld_Reject*pi/180;
        ton  = Treject_Ld_Reject;
        toff = 9999.;
       case 3
        apply_fault     = 1;
        trip_gsu        = 0;
        apply_vref_step = 0;
        pgen = Pgen_Flt;
        qgen = Qgen_Flt;
        vm = V1_Flt;
%        va = Theta1_Flt*pi/180;
        ton  = T_flt_on;
        toff = T_flt_off;
```

```
   end

   j = sqrt(-1);
   decim = 1;
   sysmva = MVA_system;

% % Operating conditions
%     pgen = 100.0;
%     qgen = 32.09;
%     vm = 1.050;
%     va = 16.602*pi/180;

va=0;

% System data
    ztran = Rt  + j*Xt;
    zline = Rl  + j*Xl;

    S = (pgen+j*qgen)/sysmva;
    v = vm*(cos(va)+j*sin(va));
    I = (S/v)';
    v3= v-(ztran+zline)*I;

% Generator data
    wo =     2*pi*fbase;
    mbase =    MVA_machine;
%     tpdo =     7.000;
%   tppdo =    0.030;
%   tppqo =    0.035;
%   h =        3.000;
%   d =        0.000;
%   ld =       1.200;
%   lq =       0.800;
%   lpd =      0.220;
%   lppd =     0.200;
    lppq =      lppd;
%     ll =       0.160;
%   s1 =       0.050;
%   s12 =      0.300;
%       ra =       0.000;

    Xd =    ld;
    Xq =    lq;
    Xpd =   lpd;
    Xppd =  lppd;
    Xppq =  Xppd;
    Xl =    ll;

    Tpdo =  tpdo;
    Tppdo = tppdo;
    Tppqo = tppqo;
    H =     h;
    D =     d;
```

```
% Init gen
    j = sqrt(-1);
    vt = vm*( cos(va) + j*sin(va) );

    zgenr = ra;
    zgenx = lppd;
    zg = zgenr + j*zgenx;

    is_r = pgen / mbase;
    is_i = qgen / mbase;

    iterm = (is_r + j*is_i)/vt;
    iterm = iterm';

    imag = abs( iterm );
    itr =   ( pgen/mbase ) / vm;
    iti = - ( qgen/mbase ) / vm;

    psir = vm + ra * itr - lq * iti;
    psii =      ra * iti + lq * itr;

    epq  = sqrt ( psir * psir + psii * psii );
    dint = atan2 ( psii, psir );
    cd = cos(dint);
    sd = sin(dint);
    eq = vm * cd;
    ed = vm * sd;
    id = itr * sd - iti * cd;
    iq = itr * cd + iti * sd;
    ppd =   eq + ra * iq + lppd * id;
    ppq = - ed - ra * id + lppq * iq;

    angle0 = va + dint;
    cd = cos( angle0 );
    sd = sin( angle0 );

    pmech = ppd * iq - ppq * id;
    pelec = pmech;

    vs_r =  ppd * cd - ppq * sd;
    vs_i =  ppd * sd + ppq * cd;

    vs = vs_r + j*vs_i;
    isorc = vs/zg;

    pfd  = ppd + ( lpd - lppd  ) * id;
    pkd  = pfd - ( lpd -    ll )*id;
    pfq  = ppq;
    pkq  = 0.;

    sa = s1;
    sb = s12;
```

```
    psi = pfd;
    if ( (sa == 0) || (sb == 0) )
        se =0.0;
    else
        a = sqrt ( sb/sa );
        b = ( 1.2 - a ) / ( 1. - a );
        a = sb/( (1.2-b)*( 1.2-b) );
        c = ( a * ( psi - b ) * (psi - b ) );
        if ( psi > b )
            se=c;
        else
            se=0.0;
        end
    end

    ladifd = pfd + (ld - lpd)*id + pfd*se;
    efd = ladifd;

% System data on gen base
    ztran = ztran*mbase/sysmva;
    zline = zline*mbase/sysmva;

% Ntwk
    Y =  zeros(3);
    Y(1,1) = 1/zg +  1/ztran;
    Y(1,2) = -1/ztran;
    Y(2,1) = Y(1,2);
    Y(2,2) = 1/ztran + 1/zline;
    Y(2,3) = -1/zline;
    Y(3,2) = Y(2,3);
    Y(3,3) = 1/zline;
    Z1 = inv( Y(1:2,1:2) );
    Z2 = Z1;

    if( apply_fault )
        Y(2,2) = 1/(Zfault+.0000001);
        Z2  = inv( Y(1:2,1:2) );
    end

    if ( trip_gsu )
        ztran = 0.0 + j*99999.;
        Y(1,1) = 1/zg +  1/ztran;
        Y(1,2) = -1/ztran;
        Y(2,1) = Y(1,2);
        Y(2,2) = 1/ztran + 1/zline;
        Z2  = inv( Y(1:2,1:2) );
    end

    IY13v3 = Y(1,3)*v3;
    IY23v3 = Y(2,3)*v3;

% Perform simulation
    sim('SMIBgensal_v1');
```

```
% % Plot simulation results
%     figure
%     subplot(3,2,1)
%     plot(Time,V1,'r')
%     grid on
%     ylabel('V_t [pu]','FontSize',9,'FontWeight','bold')
%     xlabel('Time [sec]','FontSize',9,'FontWeight','bold')
%     set(gca,'FontWeight','Bold','XMinorTick','On','YMinorTick','On')
%     subplot(3,2,2)
%     plot(Time,spd,'r')
%     grid on
%     ylabel('Speed [pu]','FontSize',9,'FontWeight','bold')
%     xlabel('Time [sec]','FontSize',9,'FontWeight','bold')
%     set(gca,'FontWeight','Bold','XMinorTick','On','YMinorTick','On')
%     subplot(3,2,3)
%     plot(Time,Pg,'r')
%     grid on
%     ylabel('P_g [pu]','FontSize',9,'FontWeight','bold')
%     xlabel('Time [sec]','FontSize',9,'FontWeight','bold')
%     set(gca,'FontWeight','Bold','XMinorTick','On','YMinorTick','On')
%     subplot(3,2,4)
%     plot(Time,Qg,'r')
%     grid on
%     ylabel('Q_g [pu]','FontSize',9,'FontWeight','bold')
%     xlabel('Time [sec]','FontSize',9,'FontWeight','bold')
%     set(gca,'FontWeight','Bold','XMinorTick','On','YMinorTick','On')
%     subplot(3,2,5)
%     plot(Time,Efd,'r')
%     grid on
%     ylabel('E_f_d [pu]','FontSize',9,'FontWeight','bold')
%     xlabel('Time [sec]','FontSize',9,'FontWeight','bold')
%     set(gca,'FontWeight','Bold','XMinorTick','On','YMinorTick','On')
```